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AEROBIC AND ANAEROBIC DIGESTION CHARACTERISTICS OF LIVESTOCK WASTES

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Final Report

AEROBIC AND ANAEROBIC DIGESTION CHARACTERISTICS OF LIVESTOCK WASTES

UNIVERSITY OF MISSOURI
SEWAGE AND INDUSTRIAL WASTE RESEARCH LABORATORY
JULY 1963

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115

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ABSTRACT

This laboratory study was initiated with the purpose of determining the aerobic and anaerobic digestion characteristics of livestock wastes. Hog, cow, and sheep manure were digested anaerobically in bench-scale digesters. First stage BOD and oxidation rate constants were measured for these same wastes. A BOD and COD correlation was determined for each waste and the rate and degree of biodegradation of hog wastes in aeration tanks was investigated.

The conclusions drawn in each phase of this study are correlated in the final chapter, and example calculations are presented for hog wastes.

The quantity of water required to treat the wastes, either aerobically or anaerobically, is considered in the final chapter, and it is shown to be a practical problem from the standpoint of the adequacy of many farm water supplies.

TABLE OF CONTENTS

Chapter

1. Introduction and Background Information..... 1
   - The Problem..... 1
   - Current Waste Handling Procedures..... 4
   - Field Inspection..... 5

2. Animal Waste Characteristics - Literature Review..... 9
   - Animal Diets and Digestion Processes..... 9
   - Feces and Urine Quantities.....14

3. Anaerobic Digestion Studies.....18
   - Purpose.....18
   - Equipment.....18
   - Hog Waste Digestion.....18
     - Preparation of Wastes for Digestion.....18
     - Hog Manure Digestion Study No. 1.....20
     - Results.....20
     - Hog Manure Digestion Study No. 2.....20
     - Discussion.....22
     - Conclusions.....25
   - Cow Waste Digestion.....25
     - Cow Manure Digestion Study No. 1.....25
     - Results.....26
     - Discussion.....29
     - Conclusions.....29
   - Sheep Waste Digestion.....29
     - Sheep Manure Digestion Study No. 1.....29
     - Results.....30
     - Discussion.....30
     - Conclusions.....33

4. Total Oxygen Demands of Livestock Wastes.....35
   - Purpose.....35
   - Carbonaceous and Nitrogenous Demand.....35
   - Procedure.....36
   - Discussion of Jug Method.....38
   - Tests.....39
   - Results.....39
   - Nitrogen Balance.....42
   - Determination of First Stage Demand and Rate Constants...44
   - Conclusions.....48

5. Laboratory Analysis of BOD and COD Characteristics of Livestock Wastes.....49
   - Literature Review on Biochemical Oxygen Demand.....49
   - Literature Review on Chemical Oxygen Demand.....49
   - Data on Samples and Sampling.....50
   - Data on Feed Rations.....50

TABLE OF CONTENTS (Continued)

Test Technique and Equipment..... 50
Test Results..... 55
Conclusions..... 59

6. Hog Waste Lagoon Study..... 61
Description of the Lagoon..... 61
Status of the Study..... 61

7. The Biodegradation of Hog Waste in Aerator Systems..... 63
Literature Review on Aeration..... 63
Test Equipment..... 64
Aerator Study No. 1..... 64
Results of Aerator Study No. 1..... 66
Aerator Study No. 2..... 73
Results of Aerator Study No. 2..... 74
Aerator Study No. 3..... 78
Results of Aerator Study No. 3..... 78
Conclusions..... 83

8. Livestock Waste Treatment Criteria..... 85
Treatment in Anaerobic Lagoons..... 85
Treatment in Aerobic Lagoons..... 86
Treatment in Multi-celled Lagoons..... 87
Treatment in Fill and Draw Aerator..... 88
Treatment in Continuous Fed Aerator..... 89

List of References..... 91

Appendix

A. Summary of Data for Each Digester in Anaerobic Digestion Study..... 95

B. Standardization of Micro-Kjeldahl Analysis.....102

C. Computation of Probable Error in BOD Determinations.....104

D. BOD, COD, and Dissolved Oxygen Determinations in Lagoon Study.....106

TABLE OF FIGURES

Figure

1. Farm Animal Population in the United States, 1939-1959..... 2
2. Annual Farm Animal Manure Production, 1939-1959..... 3
3. Typical Disposal System with Lagoon Located Adjacent to Confinement..... 8
4. Experimental Incubator and Digesters..... 19
5. Graph Showing Operating Results for Hog Manure Digestion Study No. 1..... 21
6. Graph Showing Operating Results for Hog Manure Digestion Study No. 2..... 23
7. Graph Showing Operating Results for Cow Manure Digestion Study No. 1..... 27
8. Graph Showing Operating Results for Sheep Manure Digestion Study No. 1..... 31
9. Biochemical Oxygen Demand of Livestock Wastes on Volatile Solids Basis..... 40
10. Theoretical and Experimental BOD of Hog Manure..... 46
11. Theoretical and Experimental BOD of Cow Urine and Sheep Manure..... 47
12. Transfer of Solutions..... 54
13. COD Reflux Apparatus..... 55
14. Bench-scale Aerators..... 65
15. Aerator Study No. 1 - BOD Reduction..... 69
16. Aerator Study No. 1 - COD Reduction..... 69
17. Aerator Study No. 1 - BOD-COD Ratio..... 70
18. Aerator Study No. 1 - Total Solids..... 70
19. Aerator Study No. 1 - Total and Volatile Solids - Average of 4 Units..... 71
20. Aerator Study No. 1 - BOD Reduction - Average of 4 Units..... 71
21. Aerator Study No. 1 - COD Reduction - Average of 4 Units..... 72

TABLE OF FIGURES (Continued)

22. Aerator Study No. 1 - BOD-COD Ratio - Average of 4 Units..... 72

23. Settling Characteristics of Aerator Contents - Six Day Detention..... 75

24. BOD and COD Reduction During Aerator Study No. 2..... 77

25. Settling Characteristics of Aerator Contents During Conversion to 12 Day Detention..... 79

26. Settling Characteristics of Aerator Contents - 12 Day Detention..... 80

27. BOD and COD Reduction During Aerator Study No. 3..... 82

TABLE OF TABLES

Table

1. Summary Data of Hog Lagoons Inspected on Field Trip in Columbia, Missouri area..... 6

2. Average Composition and Digestion Coefficients of Sweet Corn..... 10

3. Morrison Feeding Standards..... 11

4. Average Percentage Composition of Farm Manure Including Litter..... 16

5. The Daily Amount and Composition of Solid and Liquid Excrement Voided by Mature Animals..... 16

6. Daily Quantity and Composition of Solid and Liquid Farm Animal Wastes..... 17

7. Summary Data, Hog Waste Digestion Study No. 2..... 24

8. Summary Data, Cow Waste Digestion Study No. 1..... 28

9. Summary Data, Sheep Waste Digestion Study No. 1..... 32

10. Summary of Experimental Conditions in Jug Method BOD Studies..... 37

11. Summary Data of Oxygen Demand of Livestock Wastes by Jug Method..... 41

12. Summary of Variations of Ammonia and Nitrate Nitrogen Concentrations During Run No. 12..... 43

13. Summary of Theoretical K, L, and BOD of Livestock Wastes..... 45

14. Record of Hog Weights..... 51

15. Ration Breakdown - Pen Number 21..... 52

16. Results of BOD and COD Tests on Hog Manure..... 57

17. Results of BOD and COD Tests on Cow and Sheep Manure..... 58

18. Results of Aerator Study Number 1..... 67

19. Averages of Results - Aerator Study Number 1..... 68

20. Results of Aerator Study Number 2 - Six Day Detention..... 76

TABLE OF TABLES (Continued)

21. Results of Aerator Study Number 3 - 12 Day Detention..... 81

A-1 Summary Data, Hog Waste Digestion Study No. 2, Digester No. 3..... 96

A-2 Summary Data, Hog Waste Digestion Study No. 2, Digester No. 4..... 97

A-3 Summary Data, Cow Waste Digestion Study No. 1, Digester No. 3..... 98

A-4 Summary Data, Cow Waste Digestion Study No. 1, Digester No. 4..... 99

A-5 Summary Data, Sheep Waste Digestion Study No. 1, Digester No. 3.....100

A-6 Summary Data, Sheep Waste Digestion Study No. 1, Digester No. 4.....101

CHAPTER 1

INTRODUCTION AND BACKGROUND INFORMATION

The Problem

As the water pollution problem has become more acute, interest has been generated in the extent of pollution provided by farm animal wastes in surface run off. As this problem increases through the raising of more farm animals, it is aggravated by larger demands for water. A possible and at least a partial solution was thought to have been found where the use of lagoons was initiated in conjunction with animal confinement housing and feed parlor operation. As a waste disposal method, lagoons were introduced as a labor saving device, with little thought being given to their value in a water pollution control program.

The total farm animal populations in the United States for the years since 1939 are shown in Figure 1. The annual manure production for various farm animals is shown in Figure 2. The information used in the computation of these points is shown in Tables 5 and 6. These wastes contribute to stream pollution. The extent of the stream pollution from these sources is considered by Henderson[1] in his study of agricultural drainage and pollution in the Potomac River at Washington, D. C. From his studies, he concludes that the farm animal population equivalent, and the resulting BOD load on a particular stream, can greatly exceed the domestic sewage and industrial waste load on the stream.

Only a fraction of the total farm animal population is raised in confinement housing operations, however, no surveys to date have been made to determine the percentage. By far, the largest percentage of animals are not confined, and their waste products provide organic contamination in surface run off. This water pollution problem is most severe in areas having a large farm animal population density and these areas are most likely to be where confined feeding systems are used. In Missouri and several surrounding states, hog finishing floors are designed for 15 square feet of floor area per hog, and some finishing floors are large enough to handle 1000 hogs. At least in one case, two such buildings are utilized on one farm, and in essence, there is on this particular farm the problem of disposing of wastes from three or four people and 2000 hogs. Most hog parlors are not this large, but a few are, and it is not difficult to understand why one of the biggest

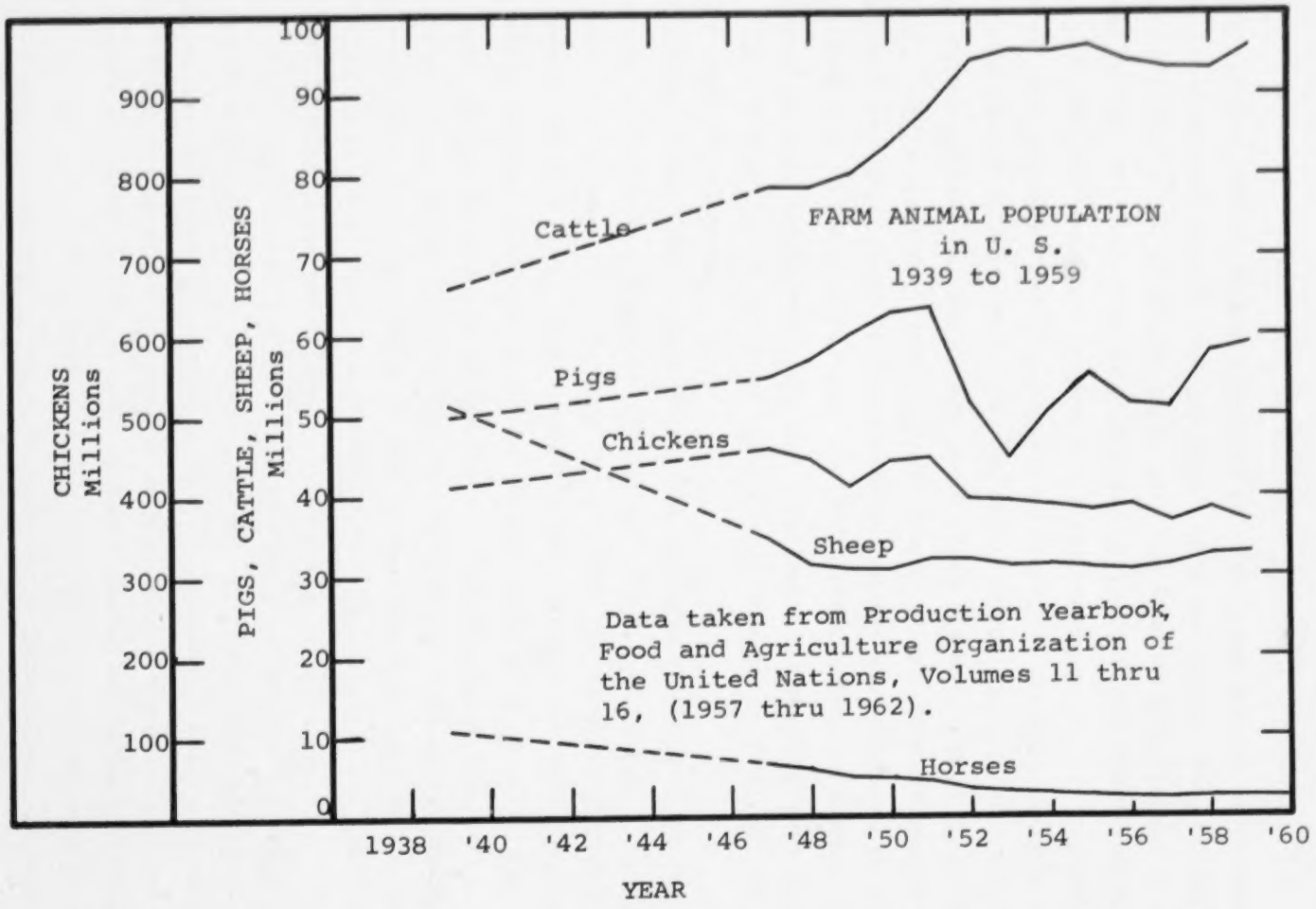

Figure 1. Farm Animal Population in the United States, 1939-1959.

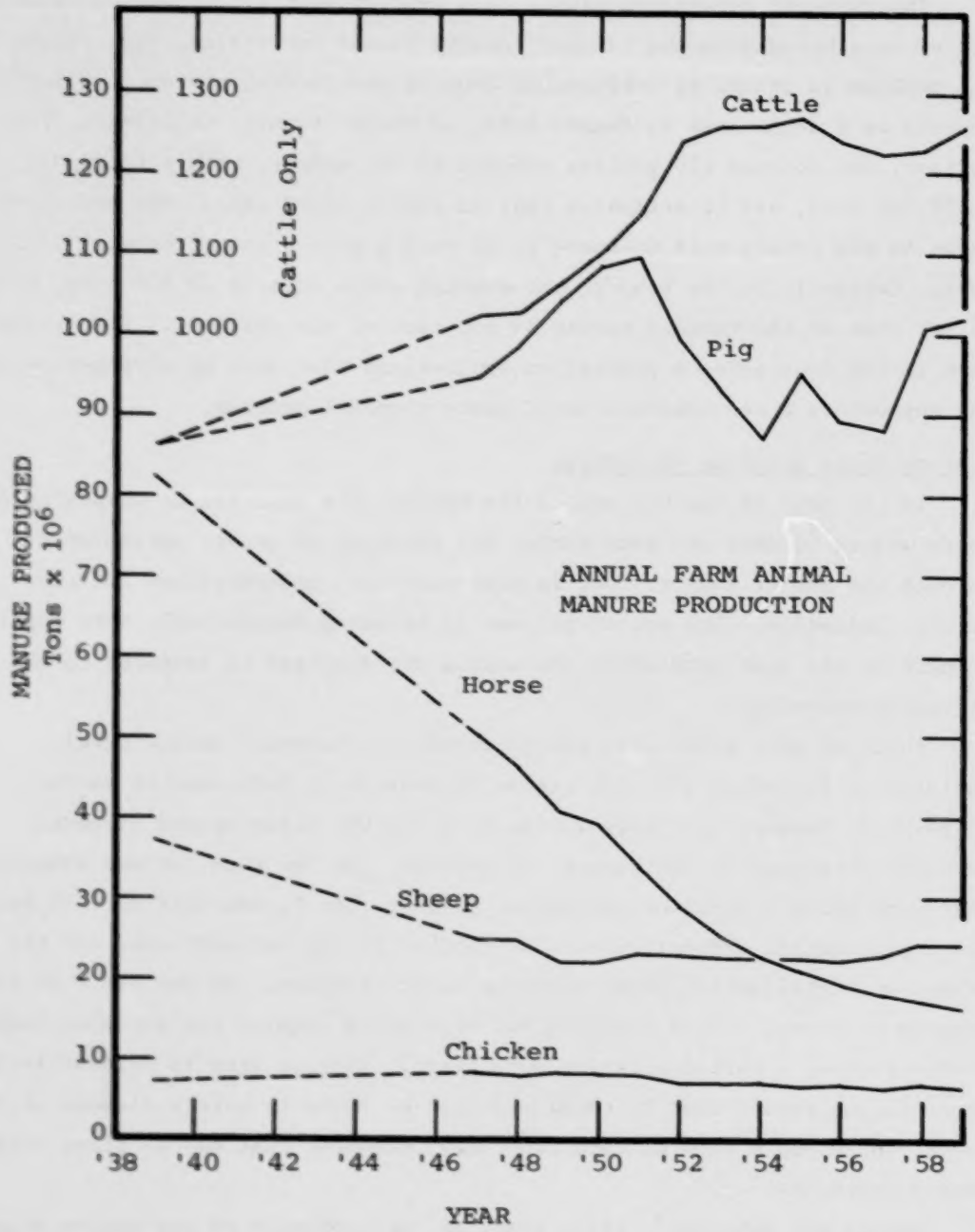

Figure 2. Annual Farm Animal Manure Production, 1939-1959.

single jobs in confinement housing of hogs is cleanup and waste disposal.

The disposal of chicken manure is a growing problem, though the number of chickens being produced in this country is not increasing, (See Figure 1). The problem is caused by confinement housing and feeding systems. Wiley[2] reports on a study made by Donald Bell, an Orange County, California, Farm Advisor, who counted 189 poultry ranches in the county, with a total of 2,528,000 hens, and he estimates that in six to eight years, the number of farms in the county will decrease to 41 with a population of about 1 million hens. Currently in the county, the average ranch size is 13,376 hens, with 45 per cent of the ranches having 80 per cent of the chickens. The average farm in the county has a population equilvalent that must be contended with and represents a considerable solid waste disposal problem.

Current Waste Handling Procedures

In the case of the hog and cattle wastes, the solution to disposing of these wastes to date has been either the practice of manure spreading or through the use of lagoons that in most cases are underdesigned for true aerobic oxidation. The use of lagoons is becoming increasingly more popular because of the ease with which the wastes are disposed of compared to the spreading operation.

Three or four years ago, the University of Missouri Agricultural Engineering Extension Division became interested in this area of waste disposal as farmers were endeavoring to solve the clean up and disposal problems presented by confinement operations. At the time, it was suspected that hogs had a population equivalent greater than 1, and that on this basis the lagoon design criteria should be similar to the criteria used for the design of stabilization ponds used for municipalities. On the basis of 250 persons per acre, a farm handling 500 hogs would require two acres of lagoon area, assuming a unit population equivalent. Such an area is prohibitively large to the farmer when he considers that he wants to merely dispose of the waste, and doesn't know or care about any treatment that may go along with lagoon operation.

Morris and Robinson[3], after studying the economics of hog manure disposal in confinement systems, state that because of the large areas required by an aerobic lagoon, "This (aerobic lagoon method) clearly will only be used by farmers who happen to have a large pond available."

Concerning manure disposal in anaerobic lagoons, designed on the basis of 35 cubic feet per hog, they state, "The least cost method of disposal, the lagoon - produced, in general, no return."

As a result of the "disposal" rather than the "treatment" philosophy, Missouri farmers were advised to construct lagoons to provide 15 square feet of surface area per hog with about a 5 foot depth. Based on farmers' satisfaction with operation, and the disposal rather than treatment philosophy, there seems to be no basis for changing the recommended 15 square feet of lagoon area per hog.[4]

Willrich[5] suggests some lagoon surface area requirements for lagoons in the Midwest based on a BOD output of 0.3 lbs per day for a fattening hog. He suggests 100 square feet per fattening hog for animal excreta where there is no bedding, and 50 square feet per fattening hog for urine with a minimum of fecal waste and no bedding.

Bussey[6] describes an integrated disposal system for disposing of cow wastes from a dairy cow herd. The wastes collected on the paved feed lot and holding pens from a 100 cow herd is "washed-down" with 5000 gallons of water over a two hour period to a lagoon designed for 150 cubic feet of lagoon per pound of BOD per day. Analysis of freshly dropped Holstein manure for COD indicated a value of very nearly 1.0 pounds of COD per pound of dry manure.

Field Inspection

A field trip was made in the early part of June, 1962, to investigate field applications of the use of lagoons in the disposal of hog wastes. Sixteen sites were visited within a 100 mile radius of Columbia, Missouri. The investigation was limited to hog lagoons, with one exception, and that was a lagoon being used to treat wastes from a milking barn.

The lagoons visited were in most cases planned to provide 15 square feet per hog with a 5 foot depth, in accordance with the recommendations of the county agents. However, as a result of the survey, it is apparent from the data in Table 1 that either the animal load was changed or many of the lagoons were not constructed as planned. The areas actually provided varied from approximately 1 to 23 square feet per hog, and the lagoon handling cow wastes provided 60 square feet per cow. This area amounts to more than 60 square feet in a sense, because only a small portion of the cows total daily waste is placed in the lagoon, while in the hog lagoons,

Table 1. Summary Data of Hog Lagoons Inspected on Field Trip in Columbia, Mo. Area.

Name	Location	Animal Waste	Number of Lagoons	Area sq. ft.	Type[1]	Number of Animals	Area/ Animal sq. ft.
Lodder	Salisbury	Hog	2 (series)	11,400 + 11,400	A	1000	
Arnsperger	Salisbury	Cow	1	5,400	A	90[2]	60
Unternaehrer	Salisbury	Hog	1	3,500	B	400	8.7
Koch	Salisbury	Hog	1	1,500	B	150	10
Bear	Higgensville	Hog	1	1,500	B	150	10
Bertz	Higgensville	Hog	1	864	C	112	7.7
Felderman	Warrensburg	Hog	1	3,750	A	250	15
Tackett	Warrensburg	Hog	1	2,700	B	260	10.4
Strobel	Dunksberg	Hog	1	3,000	B	300	10
Stephen	Longwood	Hog	1	9,000	A	400	22.5
Chamberlain	Hustonia	Hog	1	8,000	A	400	20
Chappell		Hog	1	3,200	B	700	4.6
Knaus	Sedalia	Hog	1	2,000	B	90	22.2
Scotten		Hog	1	2,000	A	160	12.5
Schoensberger	Sandy Hook	Hog	1	3,800	B	425	8.9
Paulsmeyer	Chamois	Hog	2 (series)	2,000 + 2,000	A	200	10 + 10

1. Type - A. Waste is washed through a channel or pipe to lagoon.
   B. Lagoon adjacent to pens and waste is scraped into it.
   C. Slotted floor.

2. 90 milk cows on the average

the total daily waste is placed in the lagoon. This particular lagoon had some algal growth and appeared to be in good condition.

After visiting a few of the hog lagoons, it was apparent that the lagoons were grossly overloaded and were in no way related to aerobic stabilization ponds. Septic conditions existed and there was no dissolved oxygen and little or no chance that there ever would be. There was one exception to this. The last site visited had two lagoons in series and 10 square feet per hog in each lagoon. The primary lagoon was definitely an anerobic lagoon. The secondary lagoon appeared to be aerobic, as there was some algal growth, but no dissolved oxygen analysis was made. Figure 3 shows one of the lagoons visited on the inspection trip. In the system shown, the lagoon is adjacent to the confinement pens and no water is required to wash the waste to the lagoon. The waste is just scraped into the lagoon.

In summary, some farmers did have a complaint with respect to odor. All except one, however, seemed content with the operation, and his complaint was that it required considerable time to clean the wastes into the lagoon. He proposed a return to the good old days when the hogs were in the field or a large pen and manure disposal consisted of letting it accumulate in the field.

The survey indicated that the farmers were satisfied with the lagoons to the extent that they were not interested in increasing the surface area to any great extent. It may be expected that they would submit to a design criteria of 30 or 40 square feet per hog, but to provide even 100 square feet per hog, not to mention the area that would be required for aerobic treatment, would be impossible on an economic basis, and in most cases would also be prohibitive on the basis of water availability limits.

Figure 3. Typical Disposal System with Lagoon Located Adjacent to Confinement Pens.

CHAPTER 2
ANIMAL WASTE CHARACTERISTICS

LITERATURE REVIEW

Animal Diets and Digestion Processes

Early in the anaerobic digestion experiments that are described later in this report, it was discovered that there is a wide variation in the amount of gasifiable material in various animal wastes. It is therefore advisable to consider for a moment the nutrition requirements of various animals and the digestive processes. Considerable work has been done by agriculturalists in this area, to which the best testimony is probably the over-abundance of many agricultural products.

Appendix Table III in Morrison's Feeds and Feeding,[7] gives the amounts of feed required by various farm animals depending on their weight and growth stage. It also contains much information on the nutritive value of many feeds and the nutrition requirements of many farm animals. Excerpts from Appendix Tables I and III in the book are shown in Tables 2 and 3. Table 3 shows the feeding standards for several farm animals in terms of dry matter, digestible protein, total digestible nutrients, and minerals. With this information Table 2 can be used to determine whether or not the proposed ration provides the required dry matter, digestible protein, etc. The digestible protein value of 1.5 per cent in Table 2 is obtained by multiplying the average protein content (2.3 per cent) by the protein digestion coefficient, (66 per cent). The total digestible nutrients (15.8 per cent) is obtained by adding similar products of composition and digestion coefficients for protein, fiber, nitrogen free extract and fats, remembering to multiply fat by 2.25 since its energy value for animals is approximately 2.25 times that of proteins and carbohydrates.

Thus, from these tables a feed ration or the value of a ration can be derived for practically any animal.

Another item of arithmetical interest in Table 2 is that the total dry matter is the sum of the figures describing the average total composition. The sum of percentages of protein, fat, fiber, nitrogen free extract, and mineral matter constitute the total dry matter. All of these have digestion coefficients (are digestible), except the mineral matter, and it is apparent that all of these except the mineral matter would constitute the volatile portion of the dry matter. Specifically, for sweet corn, the dry

Table 2. Average Composition and Digestion Coefficients of Sweet Corn. Excerpt from Morrison's Feeds and Feeding.[7]

All figures are in per cent.

				Mineral & Fertilizing Constitutents				Average Total Composition					Digestion Coefficients			
	Total Digestible Dry Matter	Digestible Protein	Total Digestible Nutrients	Calcium	Phosphorus	Nitrogen	Potassium	Protein	Fat	Fiber	N - Free Extract	Mineral Matter	Protein	Fat	Fiber	N - Free Extract
Corn, Sweet	24.2	1.5	15.8	-	-	0.37	-	2.3	0.8	6.9	12.2	2.0	66	78	73	64

Table 3. Morrison Feeding Standards. Excerpt from Morrison's Feeds and Feeding.[7]

Animal	Dry Matter lbs.	Digestible Protein lbs.	Total Digestible Nutrients lbs.	Calcium lbs.	Phosphorus lbs.	Carotene mg
Dairy Cow						
For Maintenance per head daily						
700-lb. cow		0.44-0.48	5.1-5.8	0.015	0.015	42
Growing beef cattle						
fed for rapid growth						
300 lbs.	7.2-9.0	0.67-0.77	5.1-6.2	0.040	0.029	20
700 lbs.	14.2-16.5	0.87-0.98	8.9-10.2	0.037	0.033	40
Fattening yearling cattle						
700 lbs.	16.5-19.1	1.36-1.52	12.7-14.3	0.044	0.040	40
Fattening lambs						
100 lbs.	2.5-3.0	0.23-0.26	2.0-2.3	0.008	0.006	5.6
Growing and Fattening Pigs						
100 lbs.	3.5-4.6	0.55-0.61	3.0-3.8	0.027	0.018	4.0
300 lbs.	7.0-8.3	0.77-0.87	5.9-6.9	0.042	0.028	12.0

matter constitutes 24.2 per cent of the raw feed of which the volatile portion is approximately $\frac{22.2}{24.2}$ = 91.7 per cent.

If it is assumed that the animal being fed sweet corn were to utilize the material to the full extent of the digestion coefficients it can be computed that the volatile portion digested is 14.97 per cent of the raw feed. This is obtained by the same computation for obtaining total digestible nutrients except for using the 2.25 factor for fat. The volatile solids remaining in the feces and urine would be 22.2 - 15 = 7.2 per cent of the raw feed. If the mineral matter remains unaffected and as 2 per cent of the raw feed, the total dry solids in the waste would be 9.2 per cent of the raw feed and the volatile portion would be $\frac{7.2}{9.2}$ = 78.3 per cent. Information from Preston[8] has indicated that a rule of thumb is that the ash in feed is generally 5 to 10 per cent, so if there is a 50 per cent reduction in organic matter, the ash concentration would be 10 to 20 per cent. In the sweet corn example above, if the digestion obtained was slightly greater than that indicated by the digestion coefficients, the waste ash portion would have been in this range.

The digestion coefficients are of particular interest as they are measured empirically by balancing the quantity of food material taken in by the animal and the quantity eliminated by the animal. Morrison[9] states, "In digestion trials, it is commonly assumed that all matter appearing in the feces represents the part of the food that is actually indigestible. This is only approximately correct, for the feces always contain in addition, some waste from the body itself, such as unabsorbed residues from the bile and other digestive juices, worn out cells and mucus from the membranes lining the digestive tract, and waste mineral matter. The feces also include innumerable living and dead bacteria."

In animals that eat much roughage, such as horses and cattle, these products form a small part of the feces, but in carnivora, such as dogs, they form a considerable part. This fact is interesting as it will be used later to help explain the small quantity of gas produced in the cow manure digestion experiment.

Roughages are feeds that are high in fiber and low in digestible nutrients. The fiber, or cellulose, forms the cell walls of plants and makes up a large amount of roughage. Pigs have simple stomachs having a single compartment. There are no enzymes produced in the digestive tract that are

able to digest this material. Ruminants, including cattle and sheep, have a compound stomach, consisting of four compartments. They can utilize large amounts of roughage because these materials are broken down by bacteria in the first three stomachs, to organic acids (mainly acetic) with the production of carbon dioxide and methane.

Concerning the resistance to digestion of some food materials, Mallette[10] states that, "The most resistant constituents of feedstuffs, from the standpoint of digestibility, are the various plant lignins, although considerable quantities of cellulose and hemicellulose also escape digestion. In the intestinal tracts of animals lignin combines with proteins (chiefly bacterial proteins) to form lignoprotein complexes, called humus. The humus of manure apparently is identical with the humus which is found in soils. It has been estimated that 25 per cent of the organic matter of cow manure is humus. "-------- During the decomposition of manure there is a simplification of numerous compounds and the synthesis of others. The final result of the synthesis of organic compounds is the formation of humus, a complex so resistant to decay that it may be considered almost stable."

The general nature of animal wastes is most succinctly described by Morrison,[11] "The undigested food and certain waste products accumulate in the rear part of the large intestine in the form of a more or less solids residue. This is expelled as the feces. The feces of farm animals consist chiefly of undigested food that has never really been within the body proper. This undigested food is mostly cellulose, or fiber, which has escaped bacterial action. Also, a portion of the other nutrients usually escapes digestion. This may be due to insufficient chewing of such food as seeds, or because some nutrients are protected from the digestive juices through being enclosed in resistant cell walls of cellulose.

"In addition to undigested food the feces also contain residues from the digestive fluids, waste mineral matter, worn-out cells from the intestinal lining, mucus, and bacteria. They may also contain such foreign matter as dirt consumed along with the food. In the case of man and of such animals as dogs and cats, the greater part of the feces consists of excretory products, rather than undigested food.

"Nearly all of the nitrogenous waste, resulting from the breaking down of protein material in the body, is excreted in the urine through the kidneys, though a trace is given off in the sweat and a more appreciable amount

in the feces. In mammals this waste chiefly takes the form of urea, while in birds it is excreted chiefly as uric acid.

"A great variety of other end-products of metabolism are likewise eliminated by the kidneys through the urine. Much of the mineral matter is excreted in the urine. However, calcium, magnesium, iron, and phosphorus are voided chiefly in the feces. Small amounts of most of the substances eliminated in the urine are also excreted by the skin through the sweat glands.

"A large amount of carbon dioxide is formed in the oxidation of the nutrients within the body for the production of heat and energy. Most of this passes into the capillaries and is carried into the blood by the veins to the lungs, where it is eliminated in breathing. A portion, however, escapes by way of the skin. Some of the methane produced by fermentations in the stomach of herbivora is absorbed into the blood and thrown out by the lungs."

Feces and Urine Quantities

There is considerable variation in information concerning quantities of wastes and solids characteristics of various farm animals. The data that is quoted most widely and that has been used over and over again, was reported by Ames and Gaither[12] in 1912. Tables 4 and 5 are reproduced from this report. Their report states that the amount of manure produced per animal varies considerably depending on the nature and amount of ration, character and quantity of litter, the economic function of the animal, and the kind of floor upon which the manure accumulates. If the feeding is done according to scientific principles, and balanced rations are used as proposed in Feeds and Feeding, the amounts of phosphorus, potassium, and nitrogen voided each day by the same animal but fed different rations, should be about the same.

Salter and Schollenberger[13] have taken the data compiled by Ames and Gaither, and computed the dry matter percentages in feces and urine for various animals. This information is shown in Table 6 with reported data compiled by other investigators. The daily production information in Tables 5 and 6 were used to compute the annual manure production shown in Figure 2.

Table 5 may be used to determine the approximate volatile solids or organic concentration in animal manure, including the litter. The organic matter percentage is calculated to be:

Horse manure	86 %
Cattle (dairy)	88.3%
Cattle (steer)	85.7%
Sheep.	86.2%

There appears to be no reported data on the organic matter in animal feces only. Some information collected in the current study is pertinent to this matter and will be discussed later.

Table 4. Average Percentage Composition of Farm Manure Including Litter. Excerpt from Ames and Gaither.[12]

	Moisture	Ash		Organic Matter		Phosphorus		Potassium		Nitrogen	
		Total	Water Soluble	Total	Water Soluble	Total	Water Soluble	Total	Water Soluble	Total	Water Soluble
Horse manure	59.16	5.30	2.120	33.04	1.540	.1080	.0570	.636	.480	.695	.365
Cattle (dairy)	79.05	2.45	1.597	18.50	1.328	.0965	.0486	.520	.504	.572	.285
Cattle (steers)	77.85	3.15	1.430	18.91	1.330	.2080	.0744	.459	.424	.726	.404
Sheep	63.61	4.97	2.473	30.73	1.988	.2230	.1300	1.010	.976	1.439	.605

Table 5. The Daily Amount and Composition of Solid and Liquid Excrement Voided by Mature Animals. Excerpt from Ames and Gaither.[12]

	Pounds Per animal		Percentage Composition					
			Nitrogen		Phosphorus		Potassium	
	Solid	Liquid	Solid	Liquid	Solid	Liquid	Solid	Liquid
Horse	35.50	8.000	.495	1.20	.13	Trace	.200	1.24
Cattle	52.00	19.400	.324	0.95	.09	.012	.124	0.79
Sheep	2.25	1.500	.650	1.68	.20	.013	.190	1.76
Hogs	6.00	3.300	.600	0.30	.20	.055	.370	0.83

Table 6. Daily Quantity and Composition of Solid and Liquid Farm Animal Wastes.

	Daily Production per Animal[13] lbs		Dry Matter per cent			
	Feces	Urine	Feces[13]	Urine[13]	Manure[7]	Feces[14]
Horses	35.5	8.0	24.3	9.9	41	
Cattle	52.0	20.0	16.2	6.2	21	16.7
Sheep	2.5	1.5	34.5	12.8	36	25.6
Hogs	6.0	3.5	18.0 (20)[15]	3.3 (6)[15]	26	33.3
Hens	0.1	-	35.0	-	75	28.4
Human	0.33[16]	-	-	-	-	23.0

7. Morrison, Frank B., "Feeds and Feeding," 21st Edition, The Morrison Publishing Company, Ithaca, New York. (1949).

13. Salter, R. M., and Schollenberger, C. J., "Farm Manure." Yearbook of Agriculture, United States Department of Agriculture, 1938.

14. Geldrick, E. E., et al, "Type Distribution of Coliform Bacteria in the Feces of Warm Blooded Animals." Journal of the Water Pollution Control Federation, 34, 3, 295 (March 1962).

15. Van Slyke, L. L., "Fertilizers and Crop Production." Orange Judd Publishing Company, Inc., p. 226 (1932).

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CHAPTER 3

ANAEROBIC DIGESTION STUDIES

The anaerobic digestion studies were undertaken for several reasons. One concern was to determine the total and volatile solids of animal manure. In view of the wide discrepancies noted in the values given in Table 6, this was believed to be necessary. The main purpose, however, was to determine the allowable loadings that could be handled in anaerobic digesters and the per cent reduction of volatile solids obtainable. Also, the quantity of gas produced during the digestion of various animal wastes was to be investigated. The results obtained in the anaerobic digestion of hog, cattle, and sheep wastes are reported in this study.

Equipment

These laboratory digestion studies were carried out in four 8 liter jars with feed, draw off and gas production lines. Figure 4 shows the laboratory incubator and digesters. Gas production was measured by a water displacement method. The incubator temperature was maintained at 95 degrees Fahrenheit in all runs.

HOG WASTE DIGESTION

Hog wastes for this study were collected from the floor of the feeding pens at the University of Missouri swine farm. The waste collected was primarily fecal waste, but it did contain some urine and a very small amount of bedding at times. It was believed to be a representative sample of the waste material that would be produced in a hog parlor operation and that would require treatment.

Preparation of Wastes for Digestion

The raw hog wastes were mixed with water in a Waring Blender to approximately a 10 per cent total solids concentration. This mixture was then analyzed for total and volatile solids concentration. The homogenizing procedure was necessary to provide a sludge on which a reproducible total and volatile solids analysis could be made. This mixture of known solids concentration was then diluted to a required total solids concentration to satisfy, simultaneously, the desired detention period and volatile loading conditions. A total and volatile solids analysis was made on the final dilution. The pH of the final mixture varied from 5.8 to 6.5, which was dependent to a large extent on the large quantity of tap water diluent.

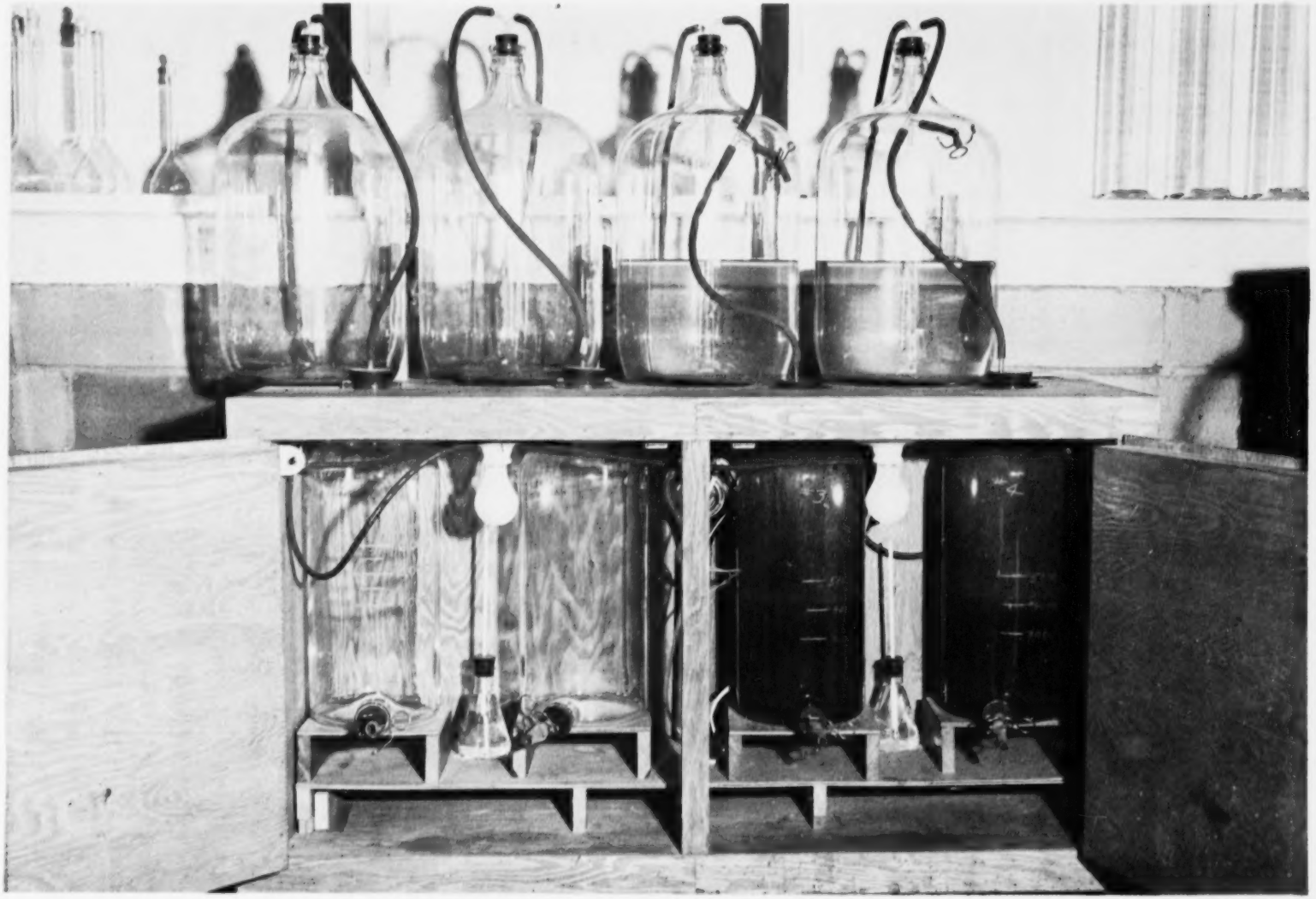

Figure 4. Experimental Incubator and Digesters.

Hog Manure Digestion Study No. 1

The first hog manure digestion study was started by using 5 liters of digested domestic sludge as seed. The sludge was obtained from the primary digester at the Columbia, Missouri, trickling filter plant. Raw domestic sludge obtained from the primary settling tanks at the same sewage treatment plant was added at the rate of 250 milliliters per day (20 day displacement), for the first 18 days of the operation. Thereafter, raw hog manure was added with the raw domestic sludge in increasing incremental amounts until the 30th day of operation, at which time the feed sludge was 100 per cent hog waste. The volume of sludge added was increased to 300 milliliters during the acclimation period. On the 31st day, when only raw hog waste was added, the feed volume was increased to 400 milliliters. This displacement was maintained until the 42nd day of operation; when the sludge feed was decreased to 100 milliliters. This reduction was made after it was evident from the increasing volatile acids concentration that the digestion process was beginning to fail.

The daily variation of volatile acids, volatile loading, pH, gas production and raw hog manure feed concentrations is shown in Figure 5. This run was proceeding with such difficulty that it was decided best to terminate it and start a new one.

Results

It is apparent from the graph that the volatile acids began to increase just prior to the cessation of the use of raw domestic sludge. The bacteria in the digester were not properly acclimated to the hog wastes. The volatile acids test was much more sensitive to the failure than was gas production, and the pH of the sludge, even at the high volatile solids concentration, never dropped below 7.0.

Hog Manure Digestion Study No. 2

The equipment, the source of raw and digested domestic sludge and the source of hog waste were the same as in the first study. The digester start up procedure differed in that the digester volume was reduced to 4 liters of seed sludge and 200 milliliters (20 day displacement) of raw sludge was added daily. The digesters were operated at a 20 day displacement period for the duration of the run. The same information that is shown in Figure 5 is shown for this run in Figure 6. The digesters, for the first 15 days,

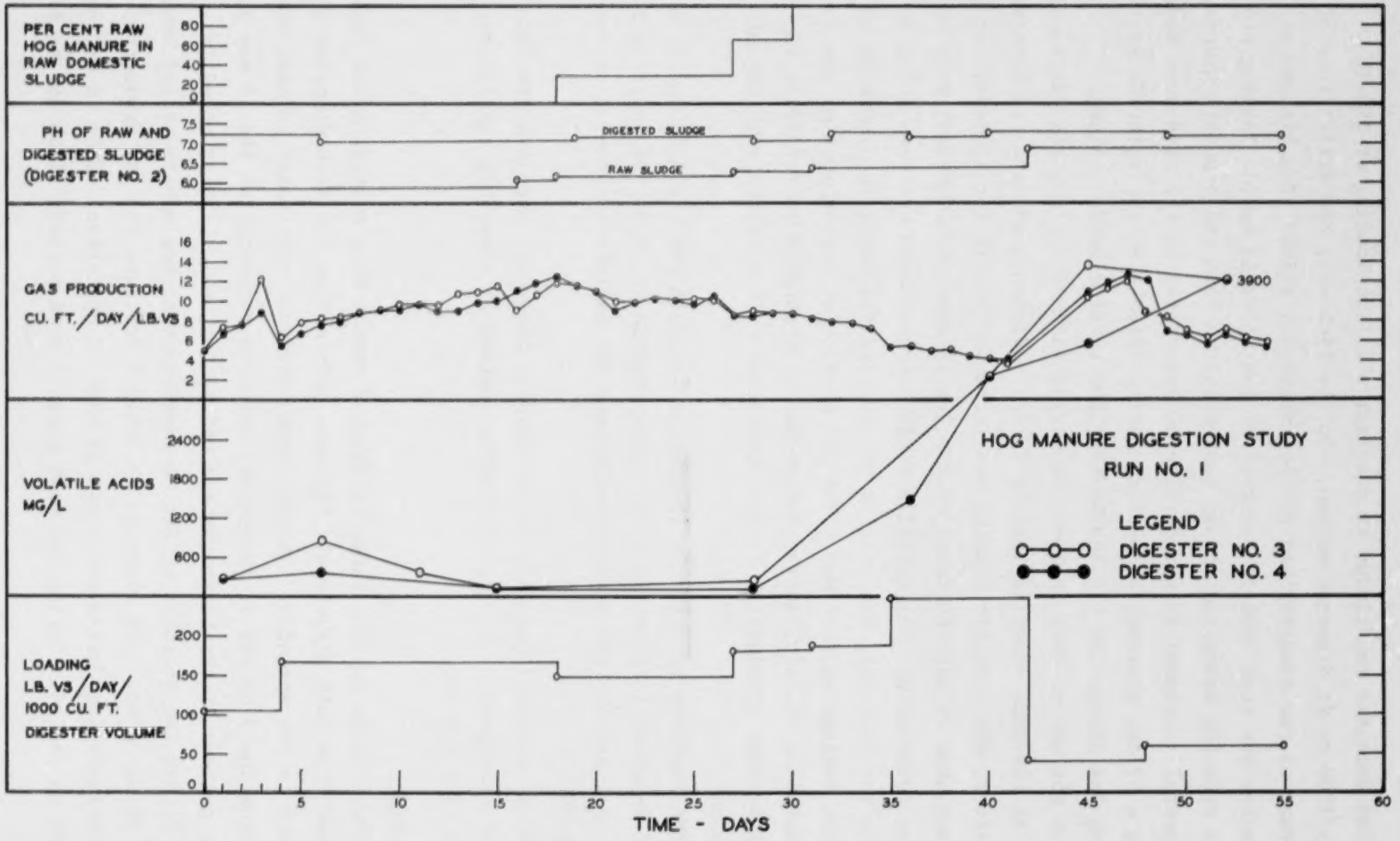

Figure 5. Graph Showing Operating Results for Hog Manure Digestion Study No. 1.

were fed domestic raw sludge at a volatile solids loading of 150 lb VS/day/1000 cu ft digester volume. On the 15th day, 200 milliliters of a mixture of raw domestic and raw hog waste was added. The mixture of the wastes was such that 15 per cent of the volatile solids loading resulted from hog waste and 85 per cent resulted from the domestic wastes. Incremental increases in the portion of hog wastes in the feed were made during a 37 day acclimation period, during which time the volatile solids loading was always 150 $\pm$ 4 lbs VS/day/1000 cu ft digester volume.

At the end of this acclimation period (52nd day), raw hog waste was added at the same volatile loading for an additional 28 days (to 80th day). Thereafter, the volatile loading was increased to 176 for 19 days, (to 99th day) and then it was increased to 200 for 12 days (to 111th day) when the run was terminated. The volatile acids concentration had been about 200 mg/l to the 80th day, but started to increase following the increase in volatile loading on that day. The gas production during most of the run and including the acclimation period had been about 8 cu ft/day/lb VS. Figure 6 shows a reduction in gas production following the 80th day of operation.

The increase in volatile loading on the 99th day was followed by a marked increase in volatile acids concentration to about 5000 mg/l on the 110th day, and the gas production dropped off rapidly to about 4 cu ft/day/lb VS.

A gas analysis was made on gas samples collected the 76th and 78th days of operation. The carbon dioxide content of these two samples was 32 and 32.5 per cent.

Discussion

The average results shown in Table 7 result from averaging the data obtained from both digesters. The same information for each digester is recorded in the appendix. The two week intervals were taken in each direction from the 52nd day of operation, and this accounts for the 11 day and 17 day periods at the beginning and end of the table. It is noted in Table 7 that the volatile solids concentration in hog manure varied from 84 to 89 per cent. The averages in Table 7 indicate the gas production is relatively low during the first 10 days of operation. This is definitely a start up period. During the next three 2 week periods (11th day to 52nd

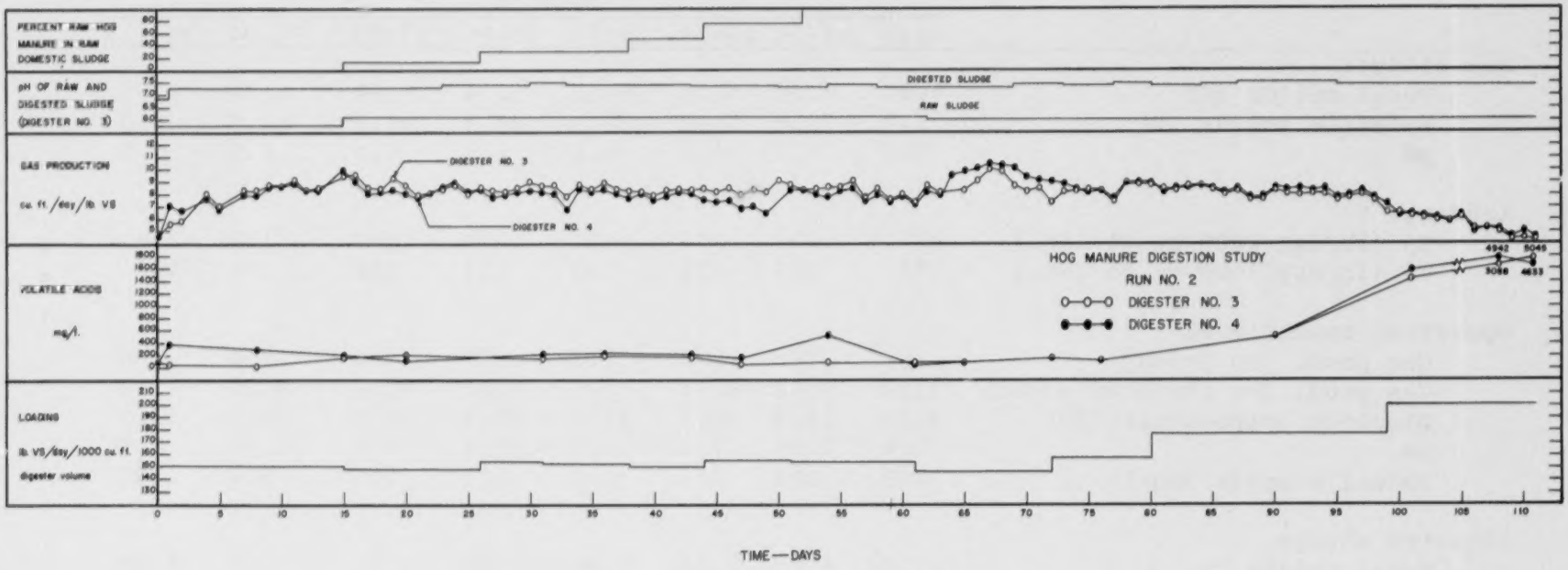

Figure 6. Graph Showing Operating Results for Hog Manure Digestion Study No. 2.

TABLE 7
Summary Data
Hog Waste Digestion Study No. 2
14 Day Average of Digesters No. 3 and 4

	Time-days							
	1-10	11-24	25-38	39-52	53-66	67-80	81-94	95-111
Raw sludge:								
Total solids (%)	6.80	6.59	6.41	6.11	5.74	5.68	6.34	6.95
Volatile solids (%)	71.0	71.8	76.0	80.3	84.4	86.9	88.5	89.0
pH	5.8	6.1	6.1	6.1	6.1	6.0	6.0	6.0
Loading:								
TS (lb/day/1000 cu ft dig.)	213	208	200	191	179	177	199	218
VS (lb/day/1000 cu ft dig.)	151	149	152	153	151	154	176	194
Operating conditions:								
Gas prod. (cu ft/day)	.155	.180	.176	.172	.176	.190	.204	.166
Gas prod. (cu ft/lb VS added)	7.29	8.63	8.21	7.96	8.26	8.78	8.22	6.12
Digester temperature (^{o}C)	35.5	35.5	35.5	35.5	35.5	35.5	35.5	35.5
pH	7.3	7.35	7.4	7.4	7.3	7.4	7.47	7.4
Volatile acids (mg/l)	203	173	193	174	121	126	514	3290
Digested sludge								
Total solids (%)	3.11	3.69	4.00	4.04	3.82	3.35	3.03	3.19
Volatile solids (%)	52.8	54.4	55.8	59.8	65.2	68.4	71.2	74.6
TS (lb/1000 cu ft dig.)	102	116	125	127	120	105	95	99
VS (lb/1000 cu ft dig.)	52	63	70	76	78	72	68	75
Reduction in TS (%)	52.2	39.7	37.5	33.7	33.0	40.9	52.5	54.6
Reduction in VS (%)	66	57.7	54	50.5	48.3	53.4	61.5	61.5
Gas prod.(cu ft/lb VS des.)	11.1	14.7	15.1	15.5	17.1	16.3	13.3	97.2

day), which includes the acclimation period, the volatile solids reduction was 52 per cent and the gas production varied from 8 to 8.6 cu ft/day/lb VS. For the next four weeks, raw hog manure was added and the gas production remained at about 8.5 cu ft/day/lb VS. After the loading was increased to 175 lb VS/day/1000 cu ft digester volume, the volatile solids reduction increased to 61 per cent while the gas production decreased to 8.22. These figures are not comparable because the digester had not been operating at the same loading long enough for equilibrium conditions to have been attained. The digestion process had started to fail in any event.

Conclusions

1. Raw hog manure has a volatile solids concentration of 84 to 89 per cent.
2. The critical loading for anaerobic digestion under the conditions of this investigation is between 150 and 170 lb VS/day/1000 cu ft digester volume.
3. The reduction on volatile solids obtained by anaerobic digestion is about 50 per cent.
4. The gas produced from anaerobically digesting hog wastes is about 8.5 cu ft/day/lb VS added or about 13 cu ft/lb VS destroyed.
5. The gas produced contains approximately 32 per cent carbon dioxide.

COW WASTE DIGESTION

The waste material used in this study was collected from a dairy herd maintained by the Department of Dairy Husbandry. The manure was collected in the feeding parlor and was free from bedding, feed, and other foreign material. The manure was diluted with water, mixed in a Waring Blender and made up to desired solids concentration in the same manner as for hog wastes.

Cow Manure Digestion Study No. 1

The laboratory digesters, the incubator, seed sludge, and start up operation were the same as for the hog waste. The digester volume was 5 liters. The displacement period was 20 days (250 ml sludge/day) for the first 49 days of operations and 16.6 days (300 ml/day) for the remaining 56 days of operation. Both digesters were operated identically. The concentration of raw cow manure in the raw domestic sludge was increased in

increments beginning the 5th day of operation; and was increased to 100 per cent during a 24 day acclimation period (5th to 29th day). The extent and duration of these loadings, along with the gas production, volatile loading, volatile acids and pH data collected during the run are shown in Figure 7. During this 24 day acclimation period, the volatile solids loading was reduced from 180 to 150 lbs VS/day/1000 cu ft digester volume. This is the same loading at which the hog waste digesters were acclimated. After the 51st day of operation, the volatile loading was then increased gradually to 218 lbs VS/1000 cu ft digester volume.

The pH of the raw sludge varied from 5.7 to 6.4. This again was probably affected by the relatively large volume of tap water used in dilution.

Results

The gas production was rather erratic for the first few days of operation during the addition of raw domestic sludge. On the 7th day following the addition of cow manure, the general trend was a reduction in gas production per unit of volatile solids added despite the simultaneous reduction in volatile loading. Following the acclimation period, the volatile loading ranged from 155 to 216 lbs VS/1000 cu ft digester volume, and the average gas production varied from 2.07 to 3.05 cu ft/lb VS added. The summary of data for this study is shown in Table 8. This gas production is approximately 40 per cent of the gas production anticipated from the digestion of domestic sludge or from hog wastes.

However, in the digestion process, the volatile solids concentration is reduced by about the same percentage. This means that the material that is biodegradable in cow manure does not have the same gas producing qualities as in hog manure or domestic sludge. This is apparent also from the data on gas produced per pound of volatile solids destroyed. The gas production data in Table 8 averages about 5.0 cu ft/lb VS destroyed. The comparable gas production for hog waste is about 15 cu ft gas/lb VS destroyed (See Table 7).

A gas analysis was made on the 47th day of operation, and the carbon dioxide concentration was determined to be 35 per cent.

The volatile acids concentration for the duration of the run was never greater than 500 mg/l. The pH of the digested sludge varied from 7.0 to 7.1.

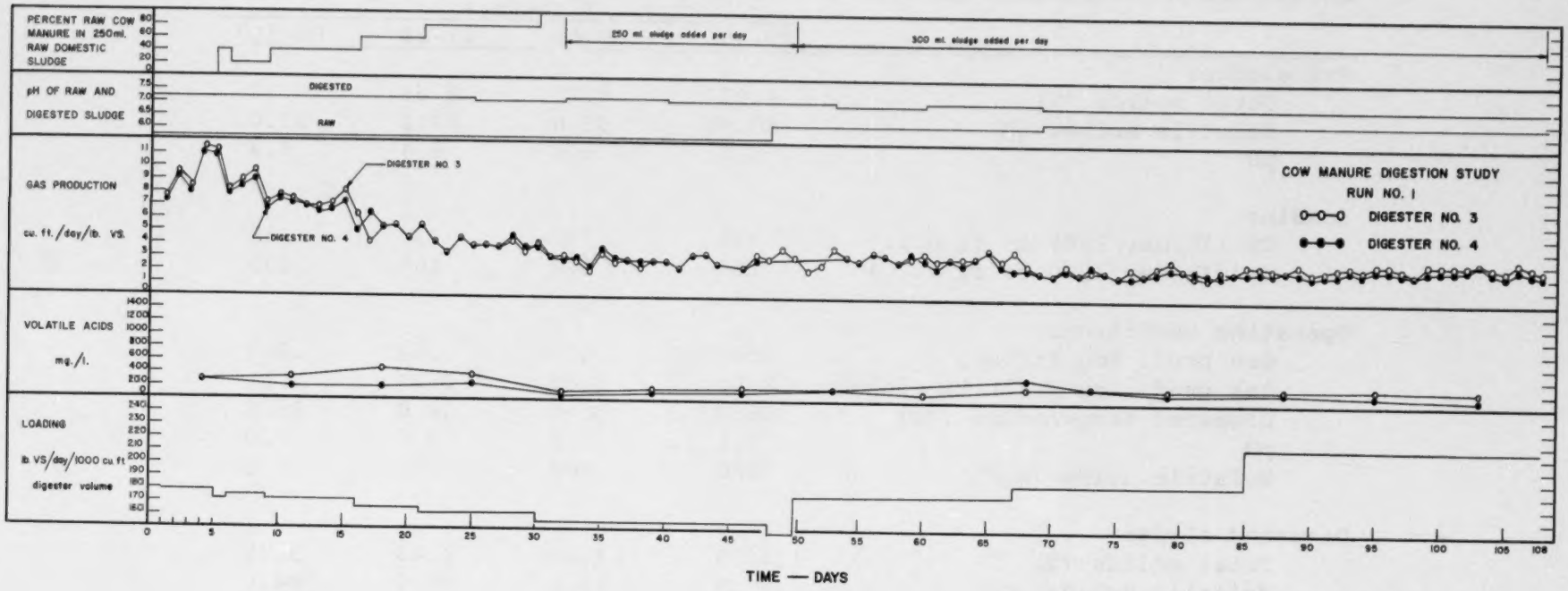

Figure 7. Graph Showing Operating Results for Cow Manure Digestion Study No. 1.

TABLE 8
Summary Data
Cow Waste Digestion Study No. 1
16 to 20 day Averages of Digesters No. 3 and 4

	Time-days			
	29-49	50-66	67-85	86-107
Raw sludge:				
Total solids (%)	4.43	4.23	4.51	5.27
Volatile solids (%)	88.9	88.6	87.3	87.0
pH	5.8	6.2	6.4	6.4
Loading:				
TS (lb/day/1000 cu ft dig.)	174	198	212	248
VS (lb/day/1000 cu ft dig.)	155	176	185	216
Operating conditions:				
Gas prod. (cu ft/day)	.065	.0745	.0545	.077
Gas prod. (cu ft/lb VS added)	2.95	3.05	2.07	2.51
Digester temperature (^{o}C)	36.0	36.0	36.0	36.0
pH	7.1	7.1	7.0	7.0
Volatile acids (mg/l)	164	162	220	176
Digested sludge				
Total solids (%)	3.75	3.49	3.43	3.79
Volatile solids (%)	74.9	83.2	85.0	84.6
TS (lb/1000 cu ft dig.)	117.5	109	113	119.5
VS (lb/1000 cu ft dig.)	88.0	90.9	91.5	101
Reduction in TS (%)	32.7	45.0	46.7	51.9
Reduction in VS (%)	42.0	48.3	47.8	53.4
Gas prod.(cu ft/lb VS des.)	6.39	6.15	4.11	4.97

Discussion

The small quantity of gas produced in this study was the most interesting observation. In the introduction of this report, the digestive process of ruminants was discussed and it was pointed out that relatively small amounts of cellulose are found in the feces of ruminants as compared to other animals, even though their diet includes large portions of roughage. Much of this material is digested in the cow's digestive system, and in the process is converted to humus, which is a very stable material as was described in Chapter 2.

Conclusions

1. The raw cow manure used in this study had a volatile solids concentration of 87 to 89 per cent.
2. The ultimate loading for a 20 day displacement period may be larger than the maximum loading of 216 lbs VS/1000 cu ft digester attained in this study. The volatile acids and pH were steady at the higher loading as well as the gas produced per pound of volatile matter destroyed. The parameters all indicate that the allowable loading is probably larger than attained in this study.
3. The reduction in volatile solids obtained in anaerobic digestion is about 50 per cent.
4. The gas production for anaerobically digesting cow manure is about 2.5 cu ft/day/lb VS added, or about 5 to 5.5 cu ft/lb VS destroyed.
5. The gas produced contains approximately 35 per cent carbon dioxide.

SHEEP WASTE DIGESTION

The waste material used in this study was collected from a sheep herd maintained on a university farm for use by the Department of Animal Husbandry. The manure was collected in the feeding parlor and was free from bedding, feed and other foreign material. There was no effort to separate the urine, so it was assumed to be mixed with the feces in about normal proportion. The manure was diluted with water, mixed in a Waring Blender and made up to desired solids concentration in the same manner as for the hog and cow wastes.

Sheep Manure Digestion Study No. 1

The laboratory digesters, the incubator, and sludge, and start up operation were the same as for the hog waste. The digester volume was 4

liters. The displacement period was 20 days (200 ml sludge/day) for the duration of the run. Both digesters were operated identically.

Sheep manure was added to the raw domestic sludge on the 16th day of operation. The sludges were mixed so that 15 per cent of the volatile load was sheep manure and the remaining 85 per cent was from the domestic raw sludge. The portion of the volatile load from sheep manure was increased in increments thereafter, as shown in Figure 8, until on the 70th day of operation the loading was 100 per cent sheep manure. The extent and duration of these loadings, along with the gas production, volatile loading, volatile acids and pH data collected during the run are shown in Figure 8.

During the acclimation period it was not possible, initially, to maintain a volatile solids loading of 150 lb VS/1000 cu ft digester without concentrating the domestic raw sludge. This was thoughtto be unnecessary, but the volatile loading was increased to 150 during the acclimation period. The digesters were operated at this loading of sheep manure for 25 days and then the volatile loading was increased to 176 for the final 18 days of operation.

The pH of the raw sludge varied from 5.8 to 6.8. This was affected by the pH of the tap water used as the diluent.

Results

The gas production was erratic during start up, which usually seems to be the case. It is seen in Figure 8 and also in Table 9, which is a summary of the bi-weekly average of the data, that the gas production continuously decreased beginning on the 16th day of operation when some sheep manure was added with the domestic raw sludge.

The gas production is considerably less than half of what would be expected from digesting domestic sludge or hog manure. As the volatile loading was increased during the last displacement period, the gas production continued to decline, as did the gas produced per pound of volatile material destroyed. The reduction in volatile solids was about 37 per cent at a volatile loading of 150, and about 33 per cent for loading of 176.

Discussion

The quantity of gas produced is relatively small, but this was anticipated as sheep are ruminants. The data compares fairly well with the

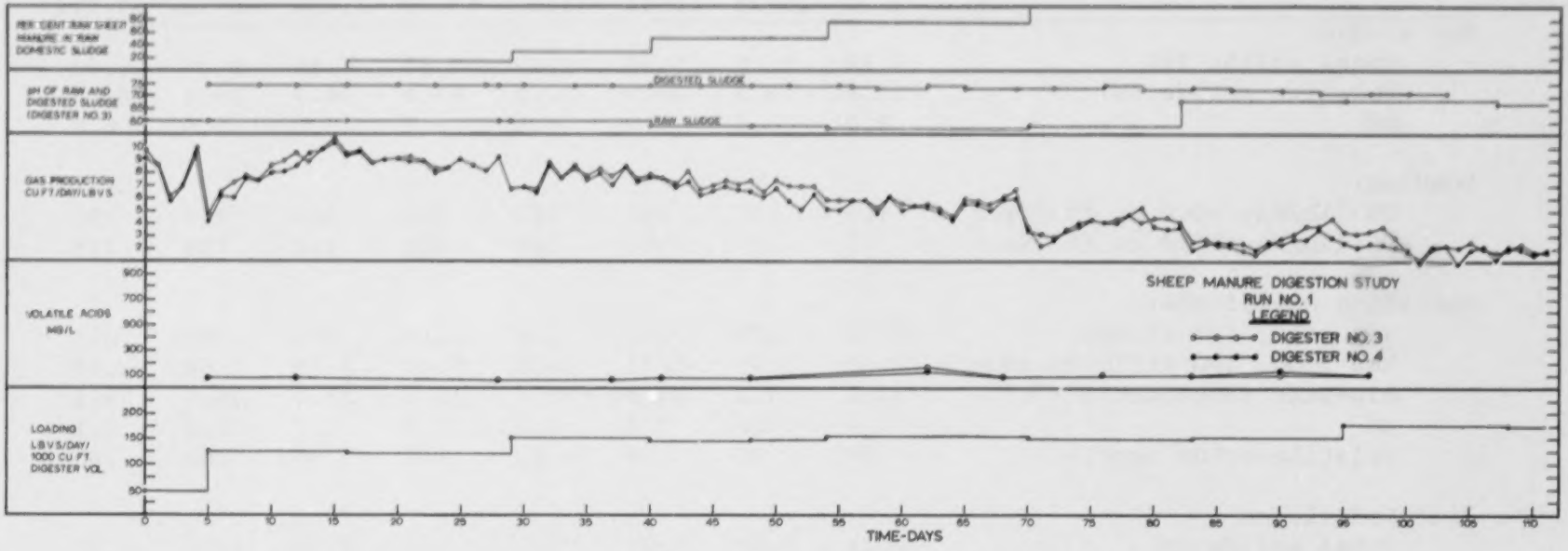
PER CENT RAW SHEEP MANURE IN RAW DOMESTIC SLUDGE
PH OF RAW AND DIGESTED SLUDGE (DIGESTER NO. 3)
DIGESTED SLUDGE
RAW SLUDGE
GAS PRODUCTION CU FT/DAY/LB V.S.
VOLATILE ACIDS MG/L
LOADING LBS V.S/DAY/ 1000 CU FT DIGESTER VOL.
SHEEP MANURE DIGESTION STUDY
RUN NO. 1
LEGEND
DIGESTER NO. 3
DIGESTER NO. 4
TIME-DAYS

Figure 8. Graph Showing Operating Results for Sheep Manure Digestion Study No. 1.

TABLE 9
Summary Data
Sheep Waste Digestion Study No. 1
14 Day Average of Digesters No. 3 and 4

	Time - days							
	1-14	15-28	29-42	43-56	57-70	71-84	85-98	99-112
Raw sludge:								
Total solids (%)	5.19	5.00	5.95	6.07	5.87	6.46	6.38	6.26
Volatile solids (%)	77.8	79.5	80.0	82.0	83.4	74.2	89.8	90.3
pH	6.0	6.0	6.0	5.8	5.7	5.8	6.8	6.8
Loading:								
TS (lb/day/1000 cu ft dig.)	125	155	186	181	184	202	176	195
VS (lb/day/1000 cu ft dig.)	97	123	149	148	153	150	158	176
Operating conditions:								
Gas prod. (cu ft/day)	.103	.157	.162	.135	.118	.075	.069	.055
Gas prod. (cu ft/lb VS added)	7.63	9.03	7.71	6.88	5.47	3.55	2.64	1.95
Digester temperature (^{o}C)	35.1	35.2	35.2	35.1	35.2	35.2	35.2	35.1
pH	7.4	7.4	7.4	7.4	7.3	7.3	7.2	7.1
Volatile acids (mg/l)	87	88	66	80	142	95	105	105
Digested sludge								
Total solids (%)	2.33	2.66	2.98	3.43	3.77	4.04	4.21	4.57
Volatile solids (%)	59.4	61.5	64.2	67.9	71.3	73.4	76.3	82.3
TS (lb/1000 cu ft dig.)	73.0	82.9	93.0	107	118	126	132	143
VS (lb/1000 cu ft dig.)	43.4	50.9	59.6	72.5	84.1	92.8	101	118
Reduction in TS (%)	41.6	46.5	50.0	40.8	35.8	36.4	25.0	26.6
Reduction in VS (%)	55.2	58.6	60.0	51.2	45.0	38.0	36.4	33.2
Gas prod.(cu ft/lb VS des.)	13.8	15.4	12.9	13.5	12.1	9.70	7.28	5.87

data for cow manure digestion, though they cannot be compared directly since the increased loading increments are not identical, and did not occur for corresponding time periods.

However, in comparing certain factors at corresponding loadings, it is seen that the results are similar. At a volatile loading of 150 for sheep and 155 for cow manure digestion, the gas productions were respectively 3.55 and 2.95 cu ft/lb VS added, the reduction in volatile solids was 38.0 and 42.0 per cent, and the gas produced per pound of volatile solids destroyed was 9.70 and 6.39 cu ft. Considering that absolute dynamic equilibrium was not obtained in either system (cow or sheep) because of changing loading conditions, these results are quite similar.

A comparison of results at a volatile loading of 176 lbs VS/1000 cu ft digester for sheep and cow manure, respectively, indicates the gas productions were 1.95 and 3.05 cu ft/lb VS added, the reduction in volatile solids was 33.2 and 48.3 per cent, and the gas produced per pound of volatile solids destroyed was 5.87 and 6.15 cu ft/lb VS destroyed.

A gas analysis was made on the 101st day of operation and indicated a 36.5 per cent carbon dioxide content.

The reasons for low gas production are the same as given for cow manure, the primary reason being that the humus produced in the intestines of ruminants is practically stable and therefore, is not available for gas production. In this sheep waste study, the lower reduction in volatile solids through the digestion process, as compared to hog manure, makes this theory more reasonable than in the cow manure study, where the reduction in volatile solids was about 50 per cent.

Conclusions

1. The raw sheep manure used in this study had a volatile solids concentration of about 90 per cent.
2. The ultimate loading for sheep manure was not reached in this study. The volatile acids did not indicate a break down in the gas producing bacteria, so it may be concluded that the ultimate loading is greater than 176 lbs VS/1000 cu ft digestion.
3. The reduction in volatile solids in the anaerobic digestion of sheep manure is dependent on the volatile loading. It

varies from 38 to 33 per cent for a volatile loading of 150 to 176 lb VS/1000 cu ft digester volume.

4. The gas production for digesting sheep waste varies from 2 to 3.5 cu ft/lb VS added depending on the volatile loading. The higher the loading, the lower the gas production. The gas produced per pound of volatile solids destroyed is about 6 to 9 cu ft.
5. The gas produced contains approximately 36.5 per cent carbon dioxide.

CHAPTER 4

TOTAL OXYGEN DEMAND OF LIVESTOCK WASTES

Purpose

The initial purpose of this phase of the study was to determine the total oxygen demand of various livestock wastes and the BOD progression rates of these wastes. After these aspects of several wastes had been studied, it was decided that the carbonaceous and nitrogenous demands should be differentiated.

The authors were able to find in the literature only limited experimental data on the BOD's and COD's of animal wastes. The animal wastes used in this study were hog, cow, sheep, and human feces, and urine from hogs and cows.

Carbonaceous and Nitrogenous Demand

The first stage or carbonaceous demand is the oxidation of carbonaceous organic matter to carbon dioxide and other products. An example is the oxidation of glucose to carbon dioxide and water.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

The second stage or nitrogenous demand is the oxidation of ammonia to nitrite and nitrates.

$$2NH_3 + 3O_2 \xrightarrow[\text{bacteria}]{\text{nitrite forming}} 2NO_2 + 2H + 2H_2O$$

$$2NO_2 + O_2 + 2H \xrightarrow[\text{bacteria}]{\text{nitrate forming}} 2NO_3 + 2H$$

The classic two step oxidation curve showing primary and secondary stages is usually observed because the nitrifying bacteria are not normally present in large numbers, and there is a resultant lag phase in nitrification during which these bacteria increase in number sufficiently to provide nitrification.[17]

The fact that the nitrogenous demand does not occur before eight to twenty days have passed, makes the 5 day BOD test in most cases a measure of carbonaceous demand only.

The nitrogenous oxygen demand of waste is frequently omitted from consideration because of this fact, and also because there is some feeling

that nitrification does not really deplete the oxygen resources of a stream. The oxygen is actually in storage and serves as a buffer against a dissolved oxygen deficit.

In a lake or lagoon however, from which there is very little if any discharge, the nitrogen would have to be converted to nitrate eventually, and even though it may be reduced when needed, its contribution to the dissolved oxygen reservoir would be a temporary one, because, eventually, it would be oxidized again to the nitrate form.

Therefore, in the case of lagoons, where there is little or no effluent, nitrogenous demands should be considered.

Procedure

The animal wastes used in this study were obtained from the same sources as were the waste samples described in Chapter 3 on anaerobic digestion studies. Care was exercised, however, to obtain feces samples not contaminated with urine. The urine samples were obtained during urination. A stool specimen was obtained from a normal, healthy, male student for the study involving human feces.

Eleven experiments, hereafter referred to as Runs 2 through 12, are reported on in this study, and the experimental procedures were practically the same for all of them. The procedure for a typical hog feces run will be described and then exceptions in other runs will be noted. The waste characteristics and experimental conditions for each of these runs are shown in Table 10.

In Run 9, a sample of hog feces collected at the swine farm was analyzed for total and volatile solids. Ten grams of the manure containing 30 per cent total solids, was thoroughly mixed with distilled water in a mixer and made up to a liter volume. This 10 gram per liter solution was analyzed for solids concentration and found to contain 0.301 per cent total solids and 74.9 per cent volatile solids.

A five gallon bottle, designated Jug No. 1, was filled with 18 liters of seeded dilution water containing 90 milliliters, (5ml/l), of seed from the primary settling tank at the Columbia, Missouri, trickling filter plant, and 90 milliliters, (5ml/l), of seed from the final settling tank. Jug No. 2 contained the same seeded dilution water as Jug No. 1 and contained in addition 180 milliliters of the 10 g/l solution of hog manure. The distilled

Table 10. Summary of Experimental Conditions in Jug Method BOD Studies.

Exp. No.	Sample	Total Solids In Raw Sample	Volatile Solids In Raw Sample	Sample Added to 1 Liter Distilled Water	Total Solids Per Liter Dilution Water	Volatile Solids Per Liter Dilution Water	Total Solids' Concentration for BOD Study
		per cent	per cent	grams	grams	grams	grams/liter
2	Hog Manure	29.2	86.0	11.88	3.44	2.96	0.0344
3	Hog Manure	27.0	86.1	12.174	3.28	2.82	0.0328
4	Cow Manure	15.15	88.1	17.872	2.70	2.38	0.0270
5	Sheep Manure	38.4	87.0	17.0	6.53	5.67	0.0653
6	Sheep Manure	34.6	89.0	38.56	13.3	11.8	0.133
7	Cow Urine	2.65	38.8	0.384 ml/lit. (6.9 ml/18 l)	0.0133	0.00515	0.0133
8	Human Feces	47.8	78.0	10.0	4.78	3.73	0.0478
9	Hog Manure	30.1	75.0	10.0	3.01	2.26	0.0226
10	Hog Manure	30.1	75.0	10.0	3.01	2.26	0.0226
11	Hog Urine	1.62	58.4	2.0 ml/lit. (36 ml/18 l)	0.0324	0.0189	0.0189
12	Hog Urine	4.27	60.0	1.5 ml/lit. (24 ml/18 l)	0.0641	0.0385	0.0385

The initial dilution in Exp. No. 2 (for example) was 11.88 grams manure at 29.2 per cent total solids mixed to one liter distilled water. This solution, therefore, contained 3.44 grams total solids per liter. This dilution was diluted 100 fold to carry on BOD studies by the jug method.

water used was obtained from the Chemical Engineering Department still. Both jugs were incubated at 20 degrees Centigrade.

In all the other manure (feces) studies, the procedure was the same except for the quantity of waste used in the initial dilution. In the case of urine, the wastes were added by volume and there was no need for the initial dilution.

In Runs 9 and 12, a nitrogen balance was attempted.

Discussion of the Jug Method

To determine the oxygen demand over an extended period of time, the jug method is quite useful.[18,19] The jugs were set up as described above, the distilled water being previously aerated to obtain a dissolved oxygen concentration near saturation. About 10 to 12 BOD bottles were filled with the sample from Jug No. 2, and the initial dissolved oxygen was determined. A similar procedure was followed with the seeded dilution water in Jug No. 1. The individual BOD bottles and the large 5 gallon bottles were incubated at 20 degrees Centigrade. The large bottles were not stoppered, but were left open to the atmosphere to minimize oxygen depletion. Each day, two of the BOD bottles were removed from the incubator and analyzed for dissolved oxygen concentration. When the dissolved oxygen content in either set of bottles (sample or seed) had decreased to 2.5 to 3 mg/l, a new set of BOD bottles was filled with the jug contents. A dissolved oxygen analysis was then made simultaneously on one bottle from the depleted and the new set. This step provides complete continuity in BOD accumulation.

Even though the contents of the large jugs were open to the atmosphere while in the incubator, the dissolved oxygen would frequently fall below 7 mg/l. When this was the case, the jug contents were aerated before filling a new set of BOD bottles. The new set of BOD bottles were again incubated until the dissolved oxygen content was depleted to 2.5 to 3 mg/l. This procedure was repeated each time there was a 5 mg/l dissolved oxygen depletion in the BOD bottles. A mass diagram of the utilized oxygen was plotted and the results were the familiar BOD curve.

The theory of the jug method is that the amount of oxygen used in the BOD bottles is the same as that used in the large bottles as long as the BOD bottles contain at least 2 mg/l dissolved oxygen.

Tests

Dissolved oxygen analyses were made using the Winkler Method according to Standard Methods.[20] The ammonia and nitrate nitrogen determinations were made by using the Direct Nesslerization Method and the Phenoldisulphonic Acid Method respectively, both methods being in Standard Methods. A microdetermination[21] of nitrogen by the Kjeldahl method was used to determine total nitrogen. The results of all nitrogen determinations are reported as nitrogen.

A standard solution of glucose-glutamic acid was used to verify the accuracy of the BOD analysis, and a standard glycine solution was used to verify the Kjeldahl analysis. The results of this standardization are given in the appendix.

Temporary standards were used for the determination of ammonia and nitrates. A Bauch and Lomb Spectronic 20 spectrophotometer was used in the colorimetric analyses.

Results

The results of these studies are plotted in Figure 9. The data is summarized in Table 11. In both cases, the reported results are corrected for the demand of the seed material. The BOD is reported as milligrams of oxygen utilized per milligram of volatile solids in the sample. These units were used rather than simply mg/l, so the results of all runs could be compared directly. There is, therefore, no problem of comparing BOD's of solutions having different solids concentrations. It is recognized that the solids concentration may, and probably does have an effect on the oxidation rate, but all the runs were made at similar solids concentrations, so it should be permissible to compare the results of various runs.

Four runs were made on different samples of hog feces. The curves, in general, are similar to each other only in shape. The 5 day BOD's vary from 0.285 to 0.720 mg O_2/mg VS. Runs 2 and 3 are similar to each other in magnitude as are Runs 9 and 10. All the runs were made in sequence and they are numbered in chronological order. Runs 9 and 10 were made several months after Runs 2 and 3, and the feces samples were collected from a different group of swine. This accounts, at least, in part for the variation between these two sets of runs on hog manure.

Two runs were made on sheep manure, and though the runs were made in sequence on different samples, they were collected from the same flock and

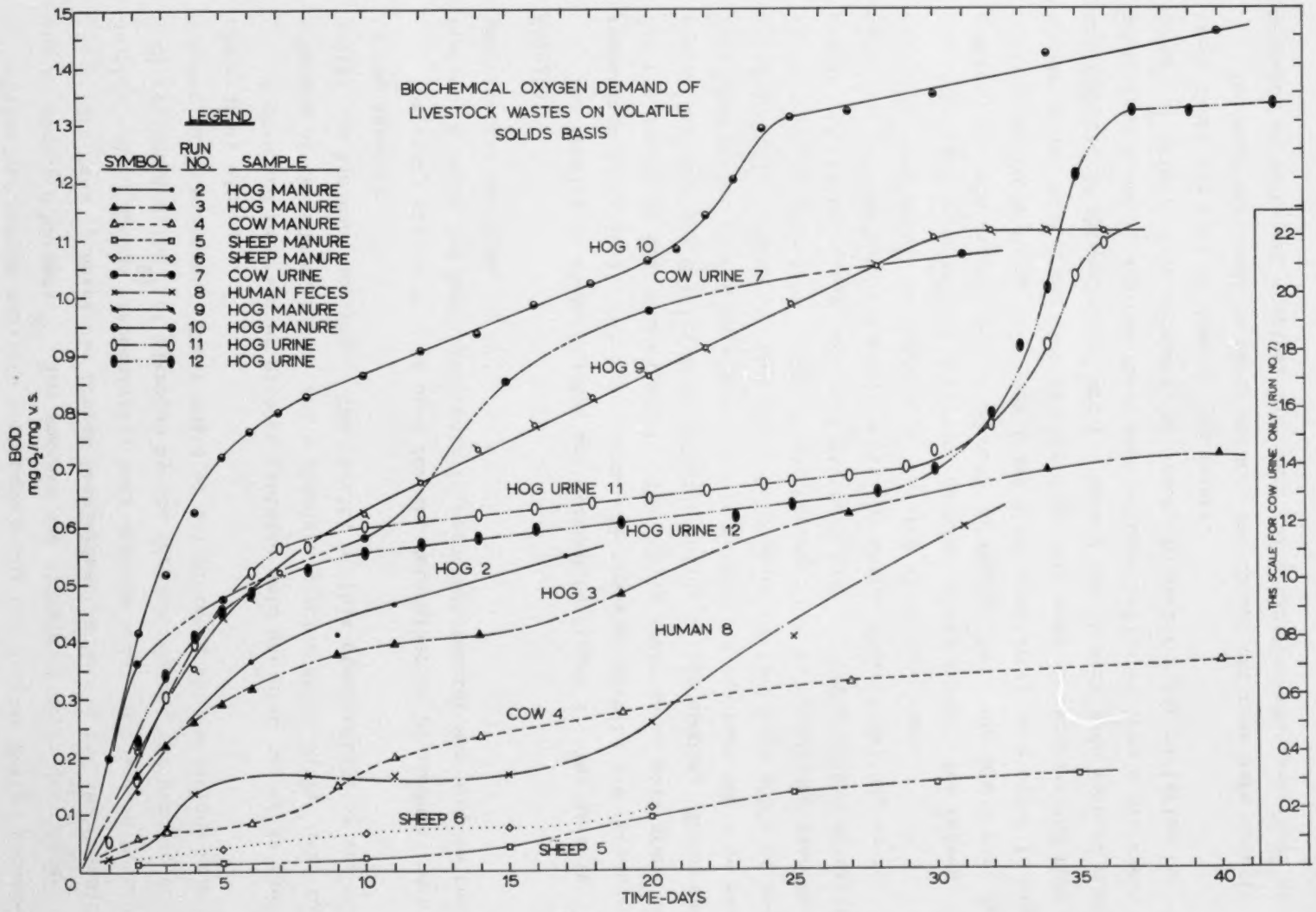

Figure 9. Biochemical Oxygen Demand of Livestock Wastes on Volatile Solids Basis.

Table 11. Summary Data of Oxygen Demand of Livestock Wastes by Jug Method.

mg O_2 / mg volatile solids

Time days	Hog Manure	Hog Manure	Cow Manure	Sheep Manure	Sheep Manure	Cow Urine	Human Feces	Hog Manure	Hog Manure	Hog Urine	Hog Urine
	Experiment No.										
	2	3	4	5	6	7	8	9	10	11	12
1	0.070						0.023		0.199	0.053	
2	0.139	0.168	0.059	0.012		0.722		0.210	0.415	0.159	0.227
3	0.226	0.220	0.068				0.070		0.517	0.303	0.341
4		0.261					0.134	0.352	0.626	0.395	0.405
5		0.290		0.014	0.039	0.942		0.443	0.723	0.471	0.451
6	0.365	0.319	0.082					0.476	0.765	0.520	0.481
7								0.520	0.798	0.563	
8							0.166		0.825	0.564	0.524
9	0.435	0.377	0.148								
10				0.021	0.065	1.16		0.620	0.861	0.599	0.551
11	0.464	0.394	0.199				0.166				
12								0.675	0.905	0.616	0.567
13											
14		0.411	0.234					0.731	0.935	0.617	0.579
15				0.040	0.073	1.70	0.166				
16								0.774	0.984	0.629	0.591
17	0.545										
18								0.821	1.02	0.636	
19		0.481	0.274								0.604
20				0.092	0.108	1.95	0.256	0.860	1.06	0.646	
21									1.08		
22								0.908	1.14	0.662	
23									1.20		0.614
24									1.29	0.670	
25				0.132			0.403	0.985	1.31	0.674	0.636
26											
27		0.620	0.325						1.32	0.682	
28								1.05			0.656
29										0.699	
30				0.149				1.10	1.35	0.728	0.695
31						2.14	0.595				
32								1.11		0.771	0.793
33											0.908
34		0.696						1.11	1.42	0.913	1.01
35				0.161						1.03	1.21
36								1.11		1.09	
37											1.32
38											
39											1.32
40		0.719	0.359						1.46		

this may account for the similarity in results. Two runs cannot provide any statistical certainty in the values obtained but it does provide a sense of magnitude.

Hog urine was tested in two runs. The results were similar except at the end of the runs where it appears that the ultimate demand in Run 11 is considerably lower than in Run 12.

Single runs only were made on cow manure, cow urine, and human feces. The cow urine demand was so large that it was necessary to reduce the vertical scale 50 per cent to accommodate the curve in Figure 9. The reduced scale at the right of this figure shows the oxygen demand for cow urine.

Nitrogen Balance

The results obtained in Runs 9 and 12 on the nitrogen balance did not balance quantitatively as anticipated. The reason for this is believed to be the large dilutions used in the jug method for total oxygen demands. The total nitrogen determinations by the Kjeldahl method were particularly erratic. The net ammonia and nitrate nitrogen determinations, corrected for seed, for Run 9 (hog manure), and Run 12 (hog urine), are shown in Table 12. The results for Run 9 are reported for the dilution at which the test was made, while the nitrogen concentrations in Run 12 are reported at the undiluted urine concentration.

The reduction in ammonia and increase in nitrate concentrations appear to occur simultaneously in Run 9, following the 20th day of the test. The continuing increase in nitrates after the complete depletion of ammonia is not readily explainable unless the ammonia produced from the organic combined nitrogen is rapidly converted to the nitrate form. At any rate, no marked effect of this nitrification is noted on the curve plotted in Figure 9.

The results obtained in Run 12, however, indicate qualitatively that nitrification began between the 23rd and 33rd day of the run. The ammonia concentration decreased following the 30th day of operation and the nitrates increased continuously from the 23rd day of the run. This nitrification is probably the cause for the sharp increase in demand on about the 28th day. It is very interesting to note that the nitrogen demand indicated on the curve in Figure 9 does not exceed the amount of oxygen that is assumed to be carbonaceous demand up to the 28th day. This is not what might be

Table 12. Summary of Variations of Ammonia and Nitrate Nitrogen Concentrations During Runs No. 9 and 12.

Hog Manure Run No. 9[a]

Days	NH_3-N mg/l	NO_3-N mg/l
1	0.05	0.02
10	0.05	0.03
20	0.04	0.04
23	0	0.08
25	0	0.20
27	0	0.66
36	0	1.04

Hog Urine Run No. 12[b]

Days	NH_3-N mg/l	NO_3-N mg/l
1	400	26.5
10	400	26.5
23	400	26.5
30	526	40.0
37	300	80.0
42	247	120.0

a. Nitrogen concentrations are given at the dilution at which the run was made. See Table 10.

b. Nitrogen concentrations are given for undiluted urine concentration.

expected, knowing that most of the nitrogen in animal wastes is excreted in the urine.

Determination of First Stage Demand and Rate Constants

A theoretical analysis of the oxygen demand data obtained from the tests on hog wastes and sheep manure was made to determine oxidation rates. The method for analysis of BOD data proposed by Moore, Thomas, and Snow[22] was used. A summary of the theoretical BOD's, the rate constants, K, and first stage demands, L, are listed in Table 13. The theoretical data and the experimental data for the hog manure runs, and for the hog urine and sheep manure runs are plotted in Figures 10 and 11 respectively. The theoretical equations are included on the graphs.

The first stage rate constants for hog feces vary from 0.06 to 0.13. The theoretical curves fit the data very well, but still remaining is the question of where first stage demand stops and second stage begins.

The rate constants for hog urine differ by 100 per cent. However, in looking at the curves, it is seen that the theoretical curve for Run 11, having the small rate constant, does not follow the experimental data as well as does the theoretical curve for Run 12. The experimental results in Runs11 and 12 do not differ by 100 per cent. Actually, they are remarkably similar.

The theoretical curve for the sheep manure follows the experimental data. The rate constant is relatively small as is the first stage demand.

A wide spread in rate constants is to be expected, not only between different animal wastes, but between oxygen demands of samples of the same type wastes. It is believed that only a pure chemical form would have a predictable oxidation rate. This is theoretically the case for glucose in the procedure used for evaluating reliability of laboratory BOD analysis by Standard Methods.[20] Even in this method, the rate constant depends to some extent on the seed material used.

The rate constant normally used for domestic sewage is 0.10. But Mohlman, et. al.,[23] reporting on the oxidation rate constants determined for sewages from several military installations found that the constants varied from 0.10 to 0.30, and the average K value observed at 16 military posts was 0.18.

It is apparent that it is not practical to try to describe the oxidation

Table 13. Summary of Theoretical K, L, and BOD[a] of Livestock Wastes. BOD and L Reported in mg O_2/mg VS.

	Run No.						
Days	2	3	6[b]	9	10	11	12
2	0.153	0.161	(5) 0.035	0.204	0.422	0.221	0.247
4	0.264	0.262	(10) 0.057	0.358	0.654	0.373	0.390
6	0.345	0.324	(15) 0.070	0.474	0.779	0.474	0.475
8	0.406	0.362	(20) 0.077	0.564	0.851	0.544	0.523
10	0.449	0.386		0.631	0.886	0.590	0.553
15	0.516	0.414		0.725	0.919	0.653	0.583
20	0.545	0.423		0.791	0.924	0.677	0.588
K	0.068	0.104	0.045	0.06	0.132	0.084	0.117
L	0.570	0.426	0.088	0.844	0.934	0.690	0.593

a) Moore, E. W., Thomas, H. A., Jr., and Snow, W. B., "Simplified Method for Analysis of B.O.D. Data." Sewage and Industrial Wastes Journal, 22, 10, 1343 (Oct. 1950).

b) Used 5th, 10th, and 15th days experimental data to determine theoretical results. On all other runs, used 1st through 7th days experimental data.

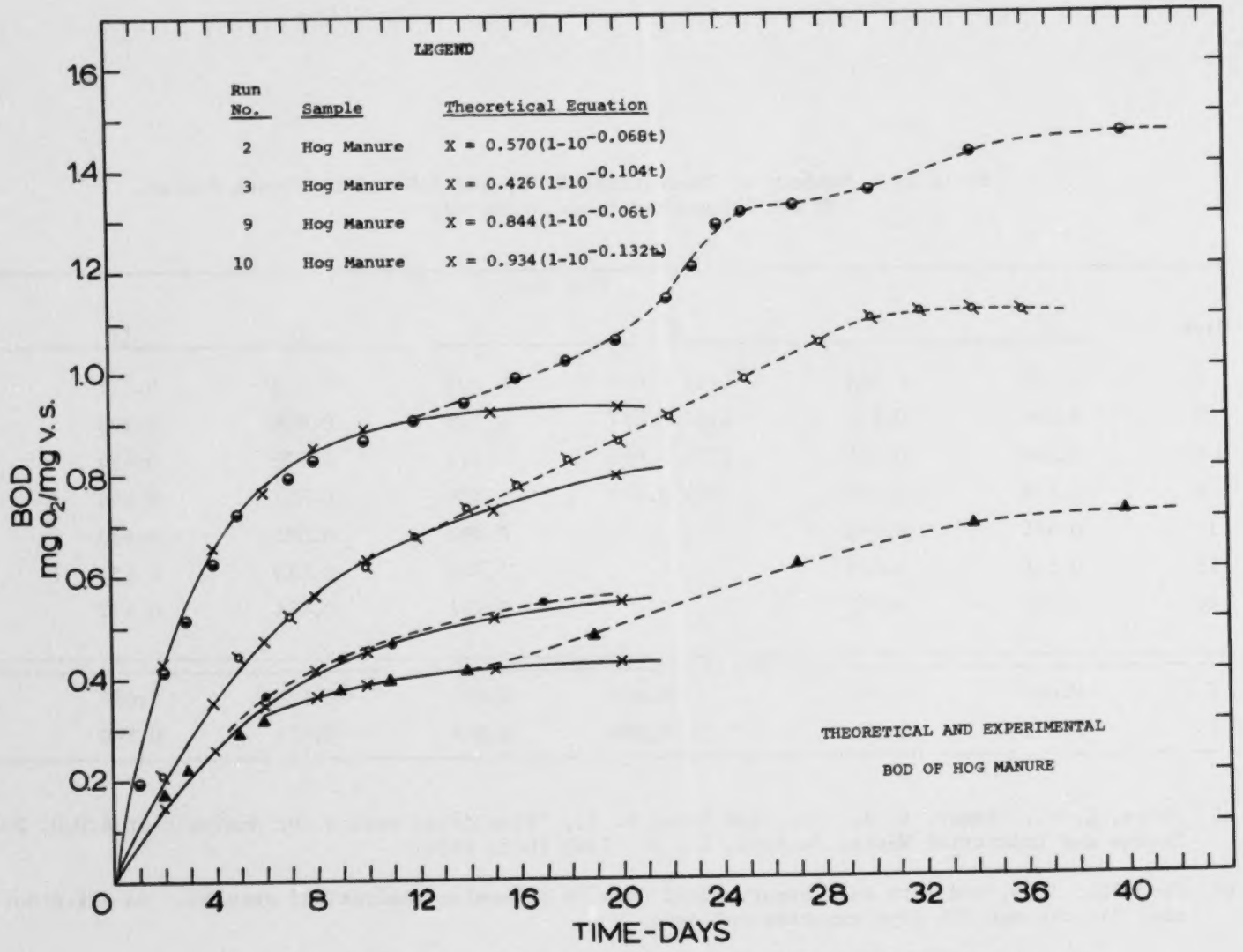

Figure 10. Theoretical and Experimental BOD of Hog Manure.

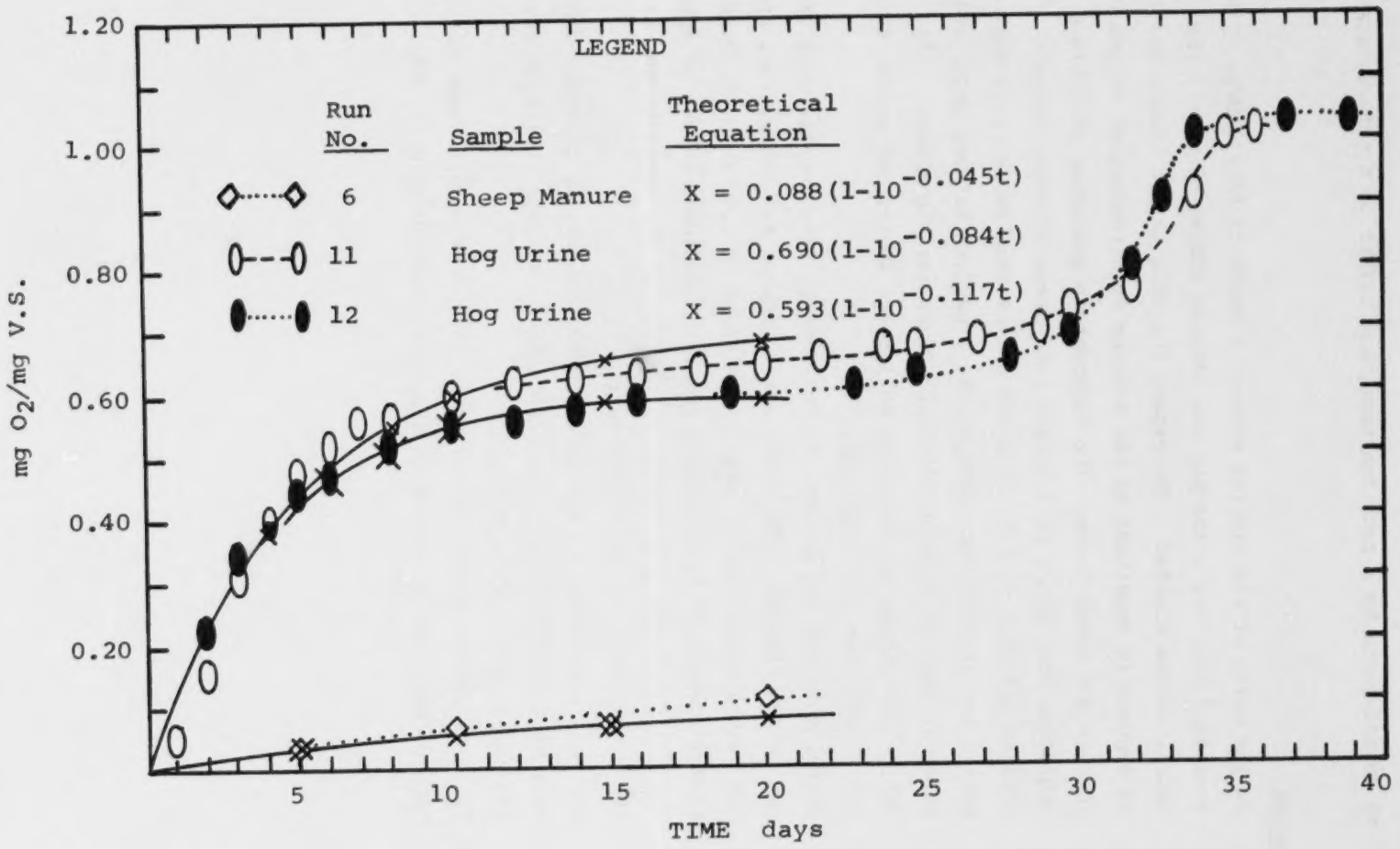

Figure 11. Theoretical and Experimental BOD of Cow Urine and Sheep Manure.

rate of an animal waste by a rate constant, but rather by a rate constant range.

Conclusions

1. On the basis of the limited number of tests in this study, it is concluded that cow urine has the largest BOD/mg VS of all the animal wastes studied. The reason for this is not known, and it is opposed in magnitude to the minimum requirements of oxygen by the cow and sheep feces. The information presented in Table 4 indicates that there is a larger percentage of water soluble organic material in cow and sheep wastes than there is in hog waste, but it does not indicate the breakdown between urine and feces or does it indicate similar values for hog wastes. If a larger percentage of dissolved solids are in the cow urine, this may account for its large BOD.
2. Sheep, cow, and hog manure, in that order, have increasingly larger oxygen demands. The first stage demands for sheep, cow, and hog wastes respectively, are in the order of 0.04 to 0.10, 0.08 to 0.10, and 0.57 to 0.93 mg O_2/mg VS. The lower values of oxygen demands for feces from ruminants are due to the large amount of humus contained in the animal waste.
3. The rate constants, K, and first stage demands, L, of these wastes vary considerably. It is concluded that the rate constants are in the range from 0.05 to 0.15.
4. The nitrogenous demand of cow urine is approximately equal to the carbonaceous demand and is in the order to 0.40 mg O_2/mg VS.

Chapter 5

LABORATORY ANALYSIS OF BOD AND COD CHARACTERISTICS OF LIVESTOCK WASTES

The intent of this study was to relate BOD and COD of livestock wastes to some parameter, such as total solids, volatile solids, etc. It became evident that precise relationships do not exist. Causes of variation are variations in feed, in animal size and age, in season of the year, variations in particle size, and in the early tests, variation in test technique.

This chapter will describe samples utilized, test equipment and technique, data on swine from which samples were obtained and feeding schedule, and will discuss the results obtained from the study.

Literature Review on Biochemical Oxygen Demand

Abbot[24] utilized the BOD to follow the course of stabilization of activated sludge, employing the fill and draw method. He stated that "although the appearance and oxygen consumed values of the supernatant from the mixed liquor steadily improved, the BOD results followed an irregular course."

Balmat[25] studied the effect of particle size upon the rate of biochemical oxidation. He concludes that the rate constant, K, probably depends, among other factors, upon the particle size. He showed that relatively large particles requiring physical diminution prior to biochemical oxidation may have a K value of 0.08, while a small particle requiring no physical diminution may have a constant of as much as 0.39.

Literature Review on Chemical Oxygen Demand

Nemerow and Ray[26] studied the BOD/COD ratio in aerator studies, using glucose as the substrate. Several significant points were made by them. One is the assumption that the COD is a measure of the total organic matter. Their aerator experiments were of short duration, being terminated after 24 hours. They obtained 35 per cent reduction in BOD in the first 6 hours, and 59 per cent reduction in 24 hours. They speculate that, since glucose was removed from the solution more rapidly than the BOD or COD was reduced, the glucose must have been incompletely oxidized and stored as some other product.

Moore, Kroner, and Ruchhoft,[27] all of whom proposed the presently used

dichromate reflux method of COD determination, state in their conclusions:

> Hydrocarbons as well as straight-chain acids and alcohols are scarcely attacked. In contrast to this, the aerobic bacteria are able to utilize and oxidize the latter two types of compounds as food. Branched-chain aliphatic acids and alcohols are, as a rule, readily oxidized by the dichromate reflux method, as well as sugars, phenols and chlorides.

Ettinger,[28] in an evaluation of the COD test, states that:

> Complete oxidation of all carbonaceous material present is not successful; specific chemicals such as benzene, toluene, and pyradine have been observed to undergo little or no oxidation under the Moore method. There can be oxidation of nitrogenous matter under certain circumstances. This leaves interpretation of present COD technique uncertain because the COD cannot be positively identified as having a definite relationship to the carbonaceous content of a sample.

He concludes, however, that "the COD test gives a relatively rapid measurement, and usually determines most of the material which can be used in completely oxidizing carbon compounds present."

Data on Samples and Sampling

The swine from which the samples were taken were confined in lean-to sheds located at the University of Missouri Swine Farm. These confinement areas provide approximately 15 square feet of floor space per hog. All samples were taken from a single pen, number 21, and care was exercised to obtain only freshly dropped fecal specimens. The weights of the animals from which samples were taken during the study are given in Table 14. Tests were distributed about evenly over the period of the weighings. Bovine feces samples were "grabbed" at milking time from the concrete floor of the University Dairy milking sheds. Sheep manure was sampled from sheds containing both adult sheep and lambs.

Data on Feed Rations

During the period of the study, the swine were fed according to the ration breakdown given in Table 15. Feeding was accomplished by self-feeders. The dairy cattle were on mixed pasture and dairy supplement. Sheep were on mixed pasture.

Test Technique and Equipment

A strong waste, such as hog manure, requires manifold dilution in order to perform the BOD and COD tests. Much of the variation in the early tests

Table 14. Record of Hog Weights.
Pounds

Hog. No.	12/20/63	12/28/63	1/4/63	1/11/63	1/18/63	1/24/63	1/31/63
1	108	109	121	129	137	144	154
2	69	72	80	90	100	106	113
3	67	72	83	89	101	108	119
4	72	79	84	91	98	105	116
5	77	78	86	93	104	107	113
6	104	108	119	128	140	145	152
7	90	100	109	116	130	136	149
No.	2/6/63	2/13/63	2/20/63	2/27/63	3/6/63	3/13/63	3/14/63
1	160	172	out				
2	123	131	144	149	162	171	out
3	127	136	148	159	166	179	out
4	122	130	137	146	157	166	out
5	124	129	140	146	155	168	out
6	157	162	175	out			
7	158	168	175	out			

Table 15. Ration Breakdown - Pen No. 21

Component	Hog Weight	
	25 - 125 lbs.	125 - 175 lbs.
	%	%
Corn	78.8	88.5
Rolled Oats	-	-
Soybean Oil Meal	15.0	7.6
Meat and Bone	5.0	2.5
Alfalfa Meal	-	-
Dried Whey	-	-
Salt	0.4	0.4
Bonemeal	0.2	0.4
Limestone	0.3	0.5
Vitamin A & D	0.05	0.05
Vitamin B	0.05	0.05
Vitamin B 12	0.05	-
Antibiotic	0.15	-

of this study was due to imperfections in laboratory technique. Initially, samples were homogenized with water, and attempts were made to manually stir the homogenized mix, and at the same time, pour a sample for solids analysis and an aliquot for further dilution. Over a period of several tests, an air-powered stirring apparatus was acquired and siphoning techniques were adapted. Originally, a 5 milliliter, large opening pipette was used for innoculation of BOD bottles. This pipette was satisfactory for small dilutions. However, serious errors occurred, for example, when a 20 milliliter dilution was required. This necessitated filling the pipette several times. A 25 milliliter, large opening, tip delivery pipette was found satisfactory. In pipetteing highly diluted suspended solids mixtures, it was not possible to adjust the volume taken up to some precise predetermined volume. Settling ensued immediately, and any of the mixture allowed to drop from the tip carried with it a disproportionate amount of solids. It was necessary to draw up a sample to the approximate volume desired and then drain the pipette completely. Figure 12 illustrates the technique and equipment used.

The above principle applies also where siphoning is employed. The mixture must be vigorously stirred and the siphonage wasted until a representative mixture is flowing. The flow is then quickly switched to the sample receiving vessel, i.e., evaporating dish or graduate cylinder.

The technique developed as best suited for the purpose was homogenization of 10 grams of wet solids (approximately 3 grams dry solids) in about 300 milliliters of distilled water, using a Waring Blender. After thorough homogenization the mix was diluted to 1 liter. Samples for solids determination were taken from this dilution. One hundred milliliters of this mix was then diluted to 1 liter, the result being a solution of about 1 gram of wet solids (0.3 grams dry solids) per liter. BOD innoculations and COD samples were taken from this solution. Results were converted back to the original 10 grams per liter basis for comparison to total and volatile solids.

BOD and COD determinations were made according to Standard Methods[20]. The dissolved oxygen content was measured by the Alsterberg (Azide) Modification of the Winkler Method.

Seed material used in the BOD tests was effluent from the primary sedimentation basin, at the Columbia, Missouri, Sewage Treatment Plant No. 2. This seed material usually has no dissolved oxygen, and a BOD value of about 160 milligrams per liter.

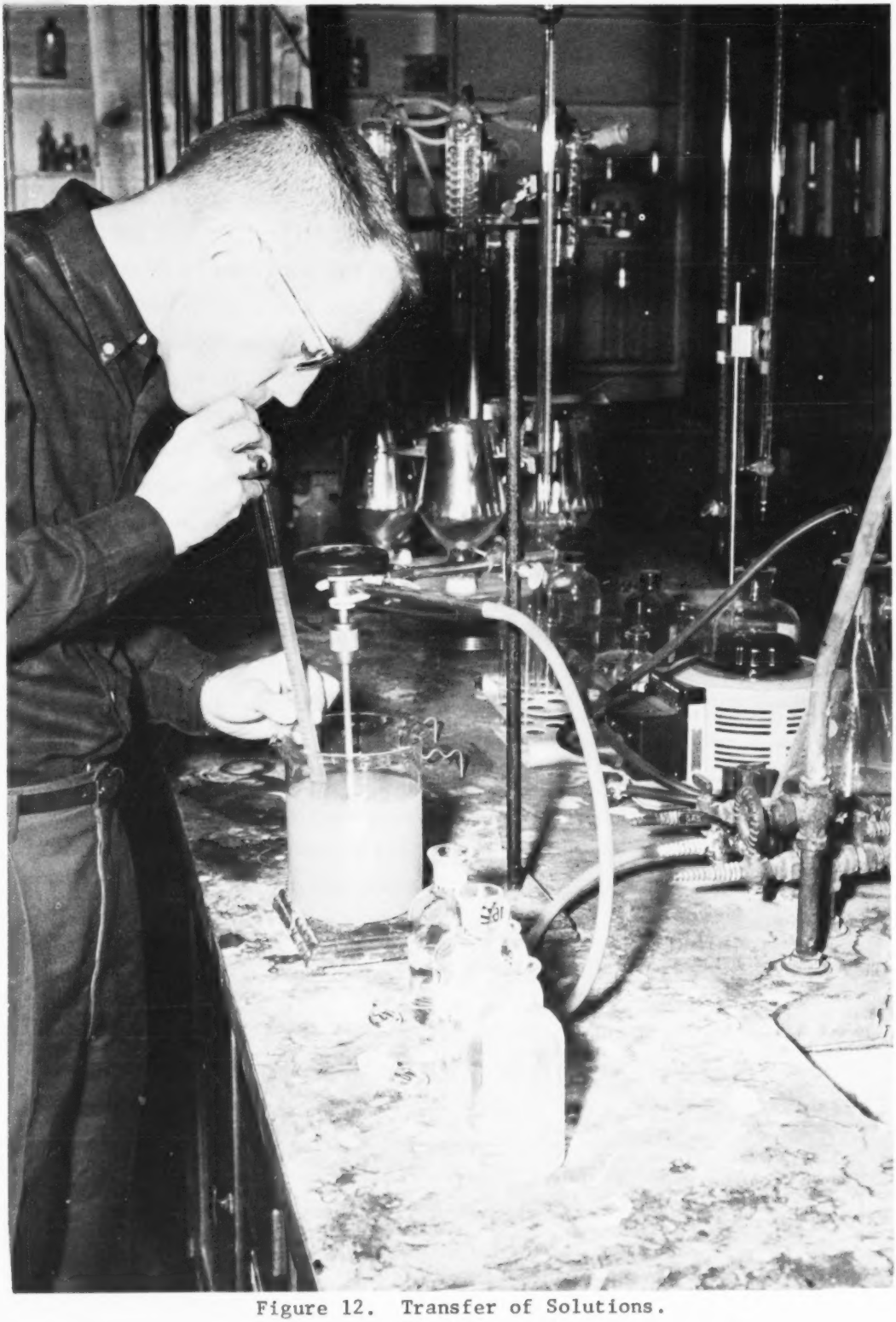

Figure 12. Transfer of Solutions.

COD determination was greatly facilitated by the utilization of the reflux apparatus developed by Luebbers.[29] This apparatus is shown in Figure 13. The apparatus employed six 250 watt heat lamps as the heat source.

Test Results

The first four sets of BOD-COD tests on hog manure were not considered in these results, due to the imperfect laboratory technique previously discussed, and the accompanying erratic results obtained. The results of later tests on hog manure are given in Table 16. Results obtained for cow and sheep manure are given in Table 17.

As may be seen from the tables, consistent results were not obtained for BOD in terms of either total solids or volatile solids. Chemical oxygen demand in terms of volatile solids was found to be the most consistent property.

A statistical analysis to reject erratic values was attempted using first .99 confidence limits, then .95 limits. For BOD in terms of total solids and volatile solids, the variations encountered were such that a large portion of the results were rejected. A lower confidence limit would have rejected fewer tests, but would have been without significant meaning. Averages for all of the properties were then taken as the resultant parameters for these studies. These averages are as follows:

	BOD $\frac{\text{mg BOD}}{\text{mg T.S.}}$	BOD $\frac{\text{mg BOD}}{\text{mg V.S.}}$	COD $\frac{\text{mg COD}}{\text{mg T.S.}}$	COD $\frac{\text{mg COD}}{\text{mg V.S.}}$	$\frac{\text{BOD}}{\text{COD}}$ %
Hog Manure	0.262	0.302	1.36	1.56	19.5
Cow Manure	0.102	0.129	1.23	1.57	8.2
Sheep Manure	0.074	0.087	1.19	1.40	6.2

The average BOD obtained for hog manure compares very well with the results reported in Chapter 4 for Runs 2 and 3, but for cow and sheep manure, the results were slightly higher. The results obtained in Runs 9 and 10 in Chapter 4 are slightly larger than 0.30 mg BOD/mg VS. It must be remembered that in these two particular runs, the larger particles remaining in the sample after homogenization were not included in the sample innoculated in the jug method. The particles that settled out rapidly were for the most

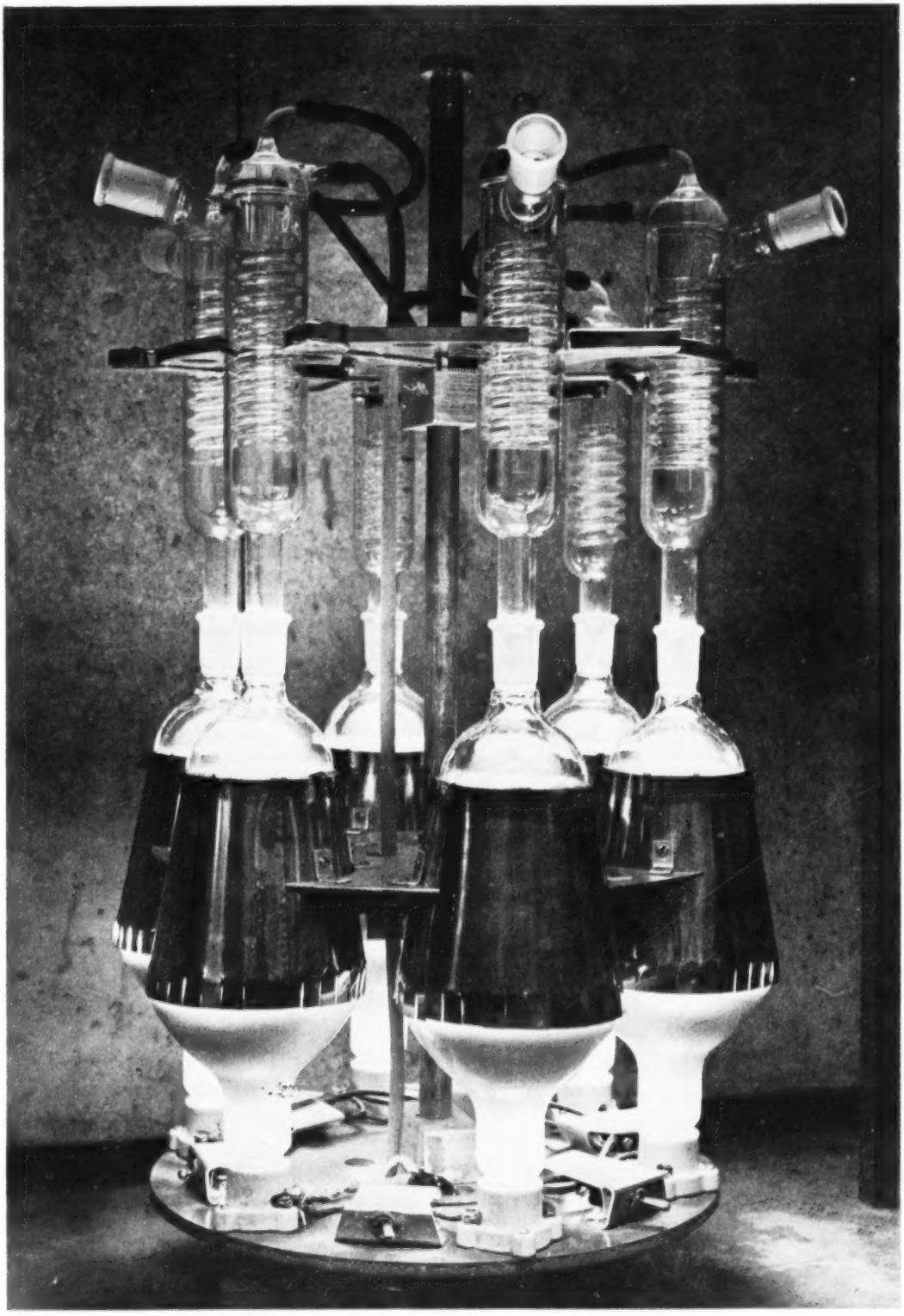

Figure 13. COD Reflux Apparatus.

Table 16. Results of BOD-COD Tests on Hog Manure.

Test No.	Total Solids	Volatile Solids	5-Day BOD	5-Day BOD	5-Day BOD	COD	COD	COD	BOD/COD
	%	%	mg/l	mg BOD / mg T.S.	mg BOD / mg V.S.	mg/l	mg COD / mg T.S.	mg COD / mg V.S.	%
5	0.238	89.4	643	0.273	0.306	3881	1.64	1.83	16.6
6	0.255	92.4	645	0.253	0.274	3610	1.41	1.53	17.9
7	0.200	87.4	546	0.273	0.312	2270	1.14	1.30	24.0
8	0.272	85.0	563	0.207	0.244	3290	1.21	1.43	17.1
9	0.246	79.9	464	0.189	0.236	3195	1.33	1.66	14.5
10	0.220	93.0	695	0.316	0.340	3265	1.45	1.56	21.3
11	0.261	88.0	577	0.221	0.251	3072	1.18	1.34	18.8
12	0.295	89.0	750	0.254	0.285	3950	1.34	1.51	19.0
13	0.280	83.9	804	0.293	0.349	3665	1.31	1.56	21.9
14	0.282	89.3	675	0.239	0.267	3805	1.35	1.51	17.7
15	0.299	89.2	957	0.319	0.358	4180	1.40	1.57	22.8
16	0.308	77.6	959	0.312	0.407	3560	1.16	1.49	27.0
17	1.009	86.3	2790	0.277	0.321	13525	1.34	1.55	20.8
18	0.354	88.1	866	0.244	0.277	6160	1.74	1.97	14.1

Table 17. Results of BOD-COD Tests on Cow and Sheep Manure.

Test No.	Total Solids	Volatile Solids	5-Day BOD	5-Day BOD	5-Day BOD	COD	COD	COD	BOD/COD
	%	%	mg/l	mg BOD / mg T.S.	mg BOD / mg V.S.	mg/l	mg COD / mg T.S.	mg COD / mg V.S.	%
*C-1	0.164	82.9	167	0.102	0.123	2020	1.24	1.48	8.3
C-2	0.140	73.9	213	0.152	0.206	1940	1.39	1.88	11.0
C-3	0.188	85.1	95	0.051	0.059	2180	1.06	1.36	4.4
*S-1	0.261	86.7	145	0.055	0.064	3300	1.26	1.47	5.4
S-2	0.294	86.0	336	0.114	0.133	3690	1.26	1.46	9.1
S-3	0.274	85.5	211	0 077	0.090	2950	1.08	1.26	7.1
S-4	0.318	83.5	162	0.051	0.061	3740	1.18	1.40	4.3

* C denotes cow manure, S denotes sheep manure.

part undigested particles of food. According to Balmat[25] the rate of biochemical oxidation is less, for large particulate matter, due to the slow rate of biochemical hydrolysis. This may explain the relatively small disparity between results. It is pointed out that 3 of the 14 samples tested in this study exceed the value obtained in Runs 9 and 10 in Chapter 4.

Disparity, which is not easily resolved, exists between the results of this study and results reported by Taiganides,[30] et al. They report BOD and COD of hog manure on a volatile solids basis, to be respectively, 0.54 and 1.20 mg O_2/mg VS. The comparable values obtained in this study are 0.302 and 1.56 respectively. They also report fluctuations in other properties with the seasons. Since their BOD and COD determinations were made in the spring, and those of this study were made in the winter, some explanation may lie therein. It is also pointed out that their BOD/COD value is 45 per cent, while that value obtained in this study is 19.5 per cent. This suggests differences in intake of feed or water or both.

The results of this study and those reported in Chapter 4 permit calculation of the organic excrement generated by a fattening hog. There is general agreement in the literature on the pounds of feces and urine voided by a hog, i.e., 6 pounds of fecal matter per day and 3.3 pounds of urine per day. There is poor agreement, however, on the total solids content of the manure. As is indicated in Table 6, the values of reported total solids concentrations varies from 18 to 30 per cent. The average of the samples collected in this study place the total solids content at 26 per cent. Results reported in Chapter 4 indicate that hog urine contains 3 per cent total solids and has a BOD of 0.27 mg BOD/mg TS. On this basis, a fattening hog exerts a total BOD of:

Feces - 6.0 lb feces/day x 26%TS x 26 lb BOD/lb TS = 0.411 lb BOD/day
Urine - 3.3 lb urine/day x 3%TS x 0.27 lb BOD/lb TS = 0.027 lb BOD/day

Total demand of feces and urine - - - - - - - - 0.438 lb BOD/day

The generally accepted per capita BOD of domestic sewage is 0.175 pounds per day. Thus a fattening hog has a population equivalent of 0.438/0.175 or 2.5.

Conclusions From the Characteristics Study

The conclusions taken from the livestock BOD and COD characteristics

study are:

1. Exacting laboratory technique is necessary for BOD and COD analysis of a strong waste, such as hog manure, which requires manifold dilution.
2. For a fattening hog being fed a ration similar to that given in Table 15, the BOD of the manure is approximately 0.26 mg BOD/mg TS or 0.30 mg BOD/mg VS.
3. The BOD of cow manure is approximately 0.10 mg BOD/mg TS, or 0.13 mg BOD/mg VS.
4. The BOD of sheep manure is approximately 0.074 mg BOD/mg TS, or 0.087 mg BOD/mg VS.
5. The characteristics of livestock wastes are variable, but not to a degree which precludes formulation of treatment processes.
6. The population equivalent of a fattening hog is about 2.5.
7. The probable error due to laboratory procedures is $\pm$ 8 per cent. The computation of this probable error is shown in Appendix C.

CHAPTER 6

HOG WASTE LAGOON STUDY

Significant numbers of hog waste lagoons are in operation throughout the Midwest. Nearly all are based upon some rule-of-thumb, such as the 15 square foot per hog criteria cited earlier. Such lagoons are potential sanitation hazards in that the effluent may pollute surface or ground water supplies. As can be seen from the theoretical calculation, presented in Chapter 8, a prohibitive land area requirement exists, insofar as the production of a non-putrescible, non-polluting effluent is concerned.

It was reasoned that a two-cell lagoon might permit the maintenance of aerobic conditions in the second cell, and thus provide an acceptable effluent. This study was conceived to investigate this possibility.

Description of the Lagoon

A second cell was added to an existing lagoon, at the University of Missouri Swine Farm. The existing lagoon was based on the 15 square foot per hog criteria. The second cell was constructed at a slightly lower elevation and approximately the same size as the primary cell. A 6 inch diameter cast iron overflow pipe was installed to control the liquid depth in the primary cell at 3.5 feet and to provide the displacement to the second cell. The overflow pipe from the secondary cell was also set to provide a liquid depth of 3.5 feet.

The lagoon is a "remote" operation, i.e., feeding is by a pipe from a collection trough near the sheds. As the pens are cleaned, the waste is dumped into a collection trough and mixed with water. The trough is then drained into the remote pipe, refilled with water, and drained again. During the period of the study, pens were cleaned three times per week, with the above routine being followed with each cleaning.

Status of the Study

This portion of the investigation has been plagued by operational difficulties to the end that, to date, no quantitative data has been obtained. Principal among these difficulties has been a water shortage at the swine farm. A greater input of water is needed to offset losses by evaporation and seepage, than can be provided by the single well at the site.

At the time of this writing, spring rains and the resultant runoff from the pen area, added to the regular water input, have provided some displacement into the second cell. No more than a slight trickle of effluent has as yet come from the secondary cell. The appearance of the primary cell is that of an ordinary hog waste lagoon having similar loading. The liquid is black, foul, and roiled by gas production. Approximately one-fourth of the surface is covered by scum. The liquid in the secondary cell contains suspended algal bloom. Aquatic life remains therein.

The small trickle of effluent has, to date, been insufficient for sampling. Therefore, no measured results can be offered.

This operation has, however, been successful to the extent that no putrescible effluent has been released. It is intended that this project be continued through the summer months of 1963. Any measurable results obtained will be appended to this report.

CHAPTER 7

THE BIODEGRADATION OF HOG WASTE IN AERATOR SYSTEMS

The purpose of this portion of the investigation was to study the biodegradation of a livestock waste under controlled conditions in bench-scale aerators, and to derive a theoretical criteria for full-scale treatment. The aeration process should not be confused with the similar activated sludge process. The latter includes final sedimentation, controlled return sludge, and a clear effluent. The effluent in this study is simply the overflow of the aeration tank contents.

Three separate studies were conducted. The first was a once-fed, batch operation, in which the rate of degradation was observed. The second and third studies were to determine optimum loadings, and to verify the theoretical optimum detention time for continuous-fed aerators, which was calculated from the results of the first study.

This chapter details the equipment, test technique, results and conclusions pertinent to these studies.

Literature Review on Aeration

Busch and Myrick[31] operated bench scale aerators in a comparison of once-fed batch systems to continuous-feed systems. The substrate used was glucose, supplemented with nitrogen and phosphorous. They pursued the total oxidation theory and confirmed that, on a practicable basis, total oxidation is not attainable. Their conclusions were:

1. No food-population equilibrium was attained in either batch or continuous system, after operation at one organic loading for as long as 103 days.
2. Biological solids in the continuous system showed cyclic fluctuations in concentration and settling characteristics.
3. Both batch and continuous systems consistently produced median effluent BOD values of less than 10 mg/l even though the continuous unit operated at loadings of up to 30 times higher than the batch unit.
4. Total oxidation is neither theoretically not practicably attainable. Some buildup of biological solids is inevitable unless effluent carryover of solids is sufficient for balance.

5. For systems of the type studied, mathematical extrapolation of batch unit data to continuous design is not practicable.

Pasveer[32] states that in present day practice, high process efficiency is being obtained in an aeration tank with an oxygenation capacity of 50 grams per hour per cubic meter, and 12 per cent floc volume after 1 hour sedimentation. He tried higher loading with increased oxygenation. At a loading of 375 lb BOD/day/1000 cu ft he obtained 95 per cent BOD removal. After increasing the loading to 3,750 lb BOD/day/1000 cu ft, the BOD removal still remained at 93 per cent.

Babbitt[33] gives periods of aeration as being from 3 to 18 hours. The optimum detention period is:

$$BOD = 20(T \neq 1)$$

where BOD is the desired removal in mg/l and T is the aeration period in hours. A dissolved oxygen concentration of 2 to 5 mg/l should be maintained at all times. This requires 1000 cubic feet of air per day per pound of BOD removed.

Steel[34] gives a criteria of 30 cubic feet of tank volume per pound of influent BOD.

Test Equipment

Four bench-scale aerators, designed to treat 10 to 12 liters of waste material, were utilized in the studies. This apparatus may be seen in Figure 14. Diffusion of air and agitation is accomplished by introducing the air at the bottom of the tank through gas diffuser stones. Water manometers were calibrated to relate head to quantity of air. A mercury manometer was also employed to permit regulation of back pressure.

Aerator Study Number 1

The first study was designed to determine optimum air volume, rate of biodegradation, and time required for total or maximum practicable degree of stabilization. The aerators were fed one uniform batch of 10 wet grams of hog manure per liter. This mix was seeded with fresh activated sludge, taken from the Columbia, Missouri, Sewage Treatment Plant Number 1. Higher loadings had been tried prior to the 10 gram loading. These had produced foaming similar to that attributed to detergents in domestic treatment plants, and the results obtained from this loading condition were not valid because the foam overflowed from the tanks and carried with it some of the

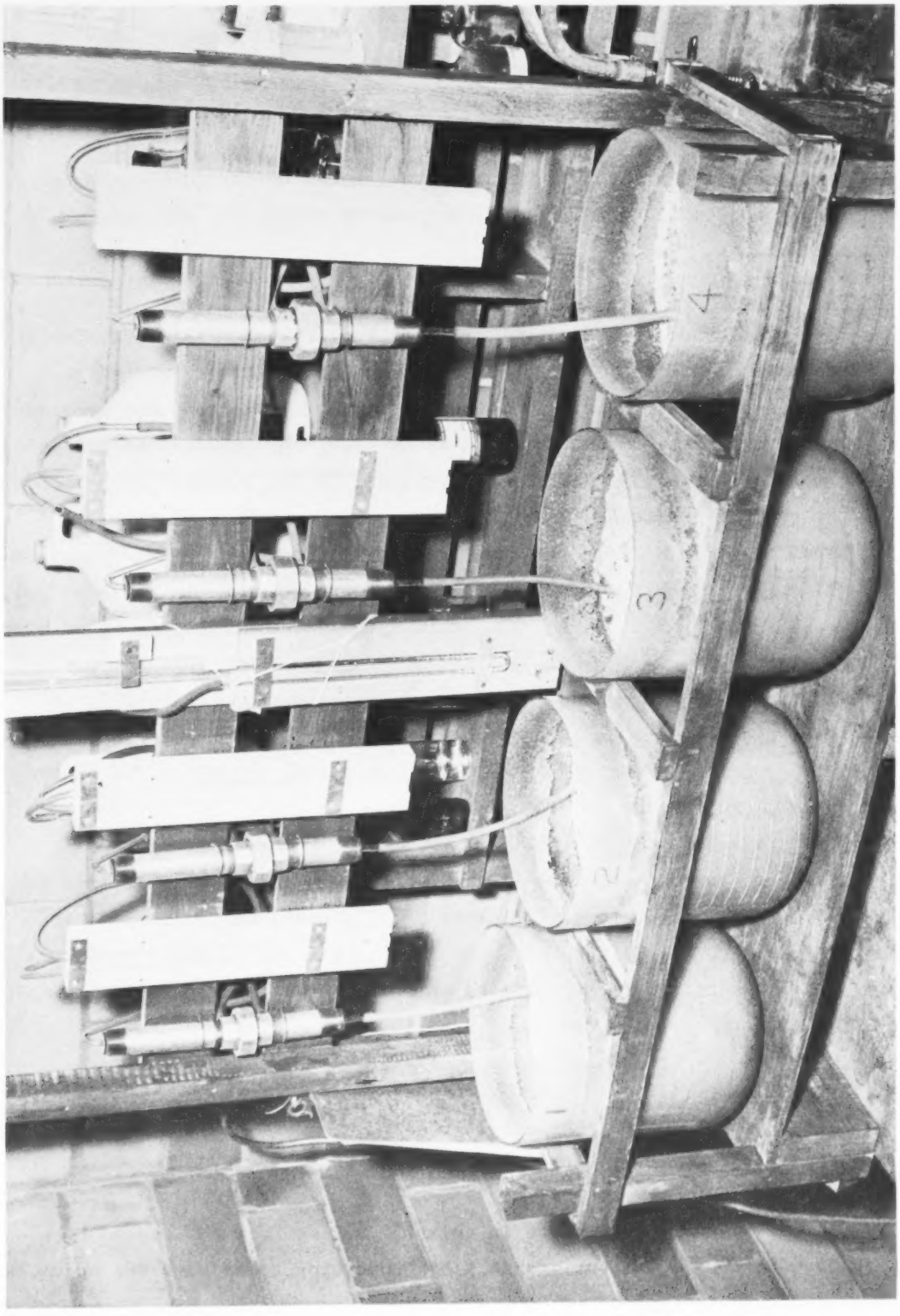

Figure 14. Bench-Scale Aerators.

solids. It was noted that after a few hours of operation the foam subsided. In the later daily-fed studies, it was found that higher solids loadings could be accommodated without excessive foaming.

The quantities of air applied were 700, 800, 900, and 1000 cubic feet of air per day per cubic foot of aerator volume.

Samples of 100 milliliter volume were removed on alternate days for analysis. The remaining portion was diluted 10 times, for BOD and COD determinations.

Results of Aerator Study Number 1

Results of these analyses are given in Table 18 and Table 19. Table 18 lists each determination for each aerator unit. Table 19 gives the average values for all units. Figures 15 through 18 portray the progression of each characteristic measured. As can be seen, the quantity of air provided, which was the only variable introduced, has no apparent correlation with the rate of biodegradation. The assumption must be made that, if not saturated, at least optimum air quantities were furnished. Since this one variable apparently has no effect, the values are averaged in Table 19 and Figures 19 through 22, and the calculations presented herein are based upon those averages.

The conclusions of Busch and Myrick[30], i.e., total oxidation is not practicably attainable, were borne out by these results. Although the COD continued to diminish the BOD became relatively constant after the sixth day.

Volatile solids may be seen to have increased during the period from the second day to the sixth day. During the same period, total solids declined. The decline in total solids is due, in part, to the removal of samples. The 100 milliliter volume of each sample was replaced by distilled water. Since a total of five samples were removed after the initial sample, the percentage of solids removed by sampling is calculated as follows:

$$\frac{500 \text{ ml removed sampling}}{10{,}000 \text{ ml aerator volume}} \times 0.308 = 0.0154$$

The actual decrease in solids, coincidentally, was 0.154 or exactly ten times the percentage removed by sampling. The remainder of the decrease is attributed to the oxidation process.

The reason for the increase in volatile solids from the second to the fifth days is not known, but probably had something to do with the accumulation

Table 18. Results of Aerator Study No. 1

Unit	Day	BOD mg/l	Corr. BOD mg/l	BOD Reduct. %	COD mg/l	Corr. COD mg/l	COD Reduct. %	Total Solids %	Volatile Solids %	BOD/COD %
1	0	1090	1090	-	3560	3560	-	0.306	78.7	30.6
	2	710	717	34.2	2400	2424	32.0	0.260	69.0	29.6
	4	362	369	66.1	2095	2137	40.1	0.235	68.1	17.2
	6	140	144	36.8	2020	2080	41.6	0.231	73.6	6.9
	8	133	138	87.4	1760	1830	48.7	0.206	70.0	7.5
	10	130	136	87.5	1190	1250	65.0	0.197	63.6	10.9
2	0	942	942	-	3760	3760	-	0.314	75.7	25.0
	2	645	652	30.8	2980	3010	19.9	0.261	68.9	21.7
	4	306	312	66.9	2330	2376	36.9	0.237	69.5	13.1
	6	168	173	81.7	2240	2307	38.7	0.220	69.5	7.5
	8	162	168	82.1	1795	1867	50.5	0.208	71.5	9.0
	10	138	145	84.6	1310	1375	63.5	0.196	62.2	10.6
3	0	902	902	-	3640	3640	-	0.295	76.7	24.8
	2	527	532	41.2	2120	2141	41.2	0.247	71.4	25.0
	4	251	256	71.9	1900	1938	46.8	0.244	74.0	13.2
	6	108	111	88.1	1920	1978	45.7	0.212	75.3	5.6
	8	101	105	88.7	2270	2360	35.2	0.250	63.5	4.5
	10	129	135	76.7	1665	1750	52.0	0.200	64.6	7.8
4	0	903	903	-	3280	3280	-	0.316	79.1	27.6
	2	636	643	28.8	2590	2616	20.2	0.252	71.5	24.4
	4	230	235	74.1	2350	2397	27.9	0.257	75.3	9.8
	6	155	159	82.5	2280	2350	28.4	0.225	73.1	6.8
	8	84	87	90.5	1700	1768	46.2	0.224	64.0	4.9
	10	57	60	93.5	1350	1418	51.9	0.193	64.8	4.2

Table 19. Average of Results - Aerator Study No. 1

Day	BOD mg/l	Corr. BOD mg/l	BOD Reduct. %	COD mg/l	Corr. COD mg/l	COD Reduct. %	Total Solids %	Volatile Solids %	BOD/COD %
0	959	959	-	3560	3560	-	0.308	77.6	27.0
2	629	635	33.9	2730	2757	23.4	0.258	70.2	25.1
4	287	293	69.6	2170	2212	38.6	0.243	71.7	13.3
6	143	147	84.9	2110	2173	39.7	0.222	72.8	6.7
8	120	125	87.1	1880	1955	45.7	0.222	67.2	6.5
10	113	119	87.8	1380	1450	59.9	0.196	63.8	8.4

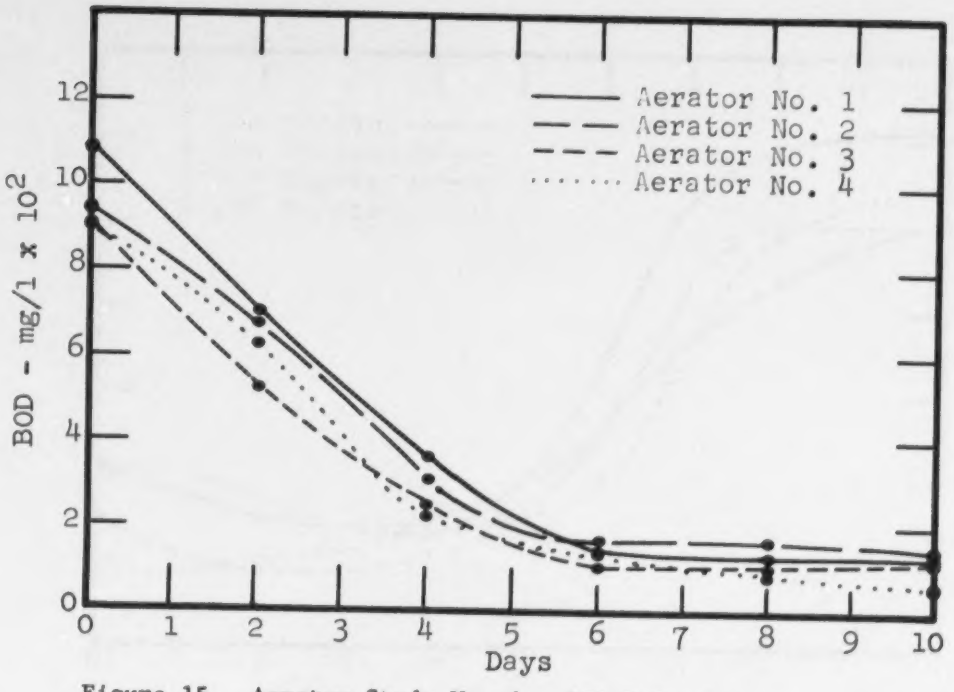

Figure 15. Aerator Study No. 1 - BOD Reduction.

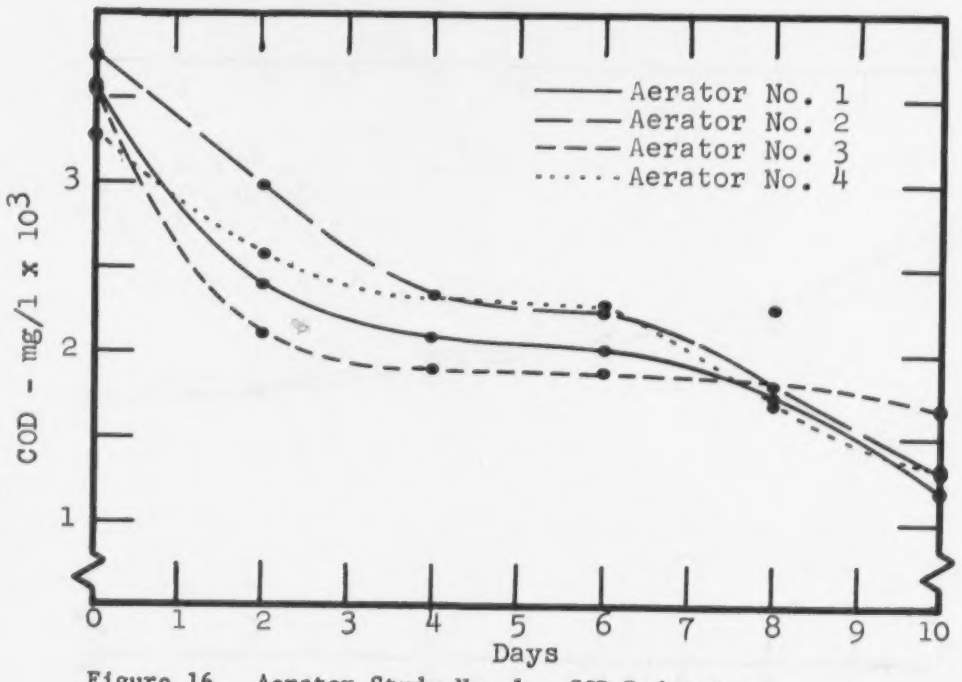

Figure 16. Aerator Study No. 1 - COD Reduction.

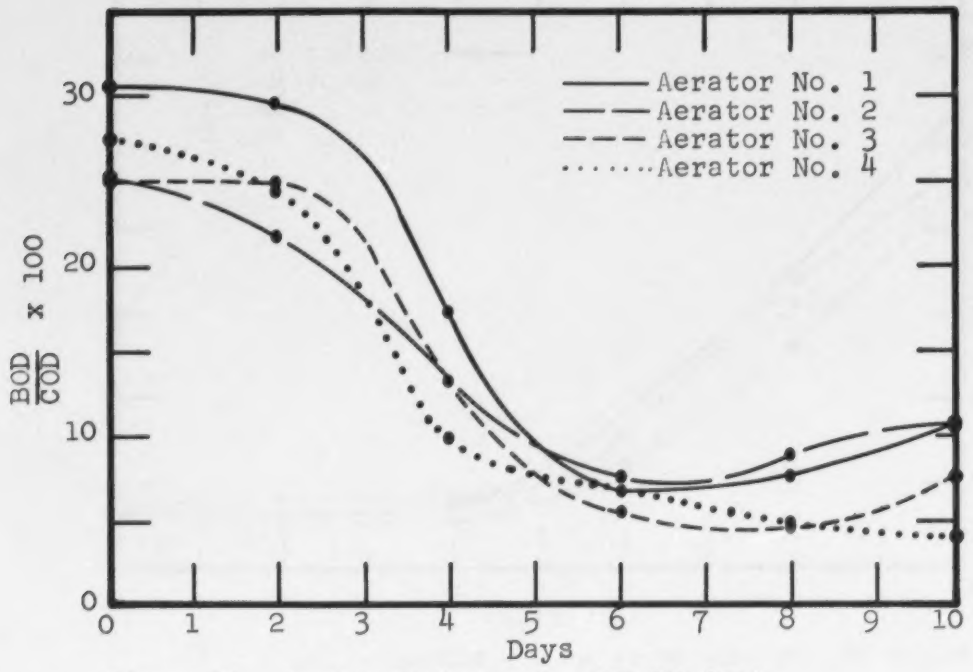

Figure 17. Aerator Study No. 1 - BOD-COD Ratio.

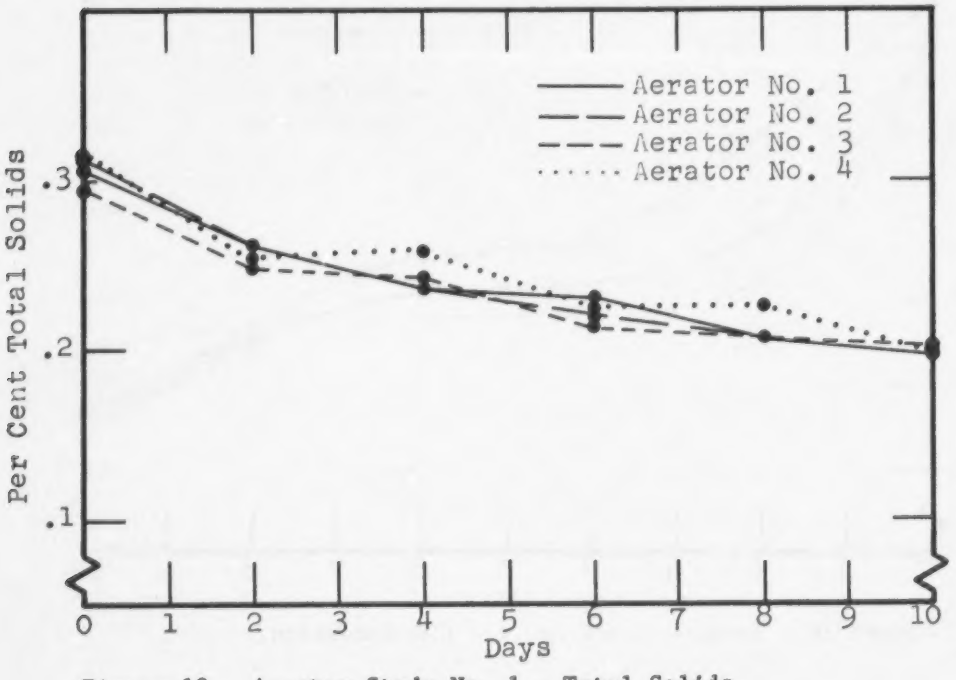

Figure 18. Aerator Study No. 1 - Total Solids.

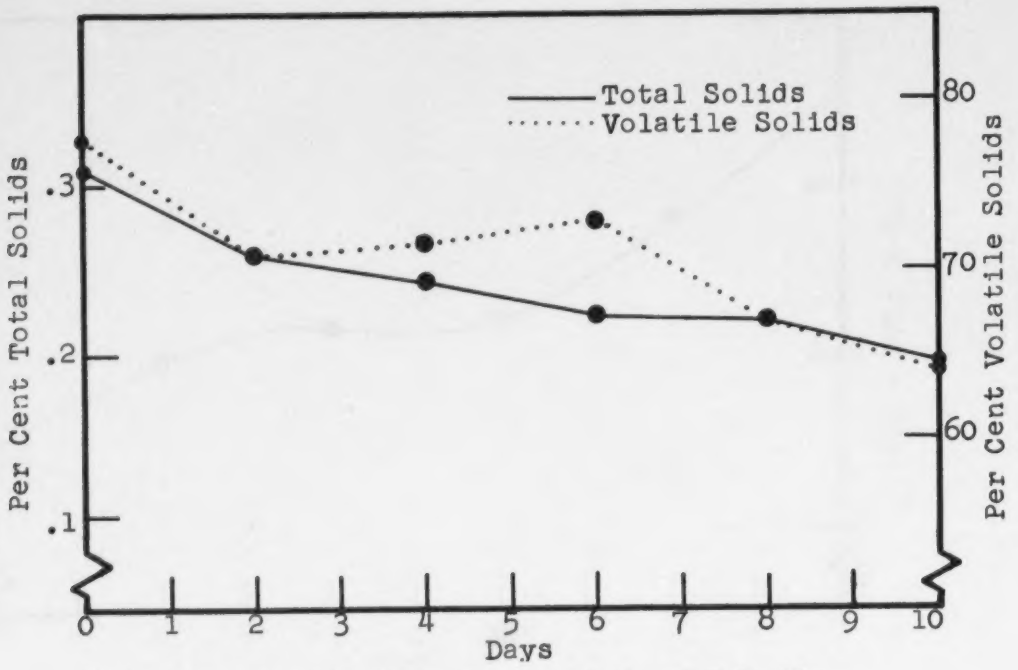

Figure 19. Aerator Study No. 1 - Total and Volatile Solids - Average of 4 Units.

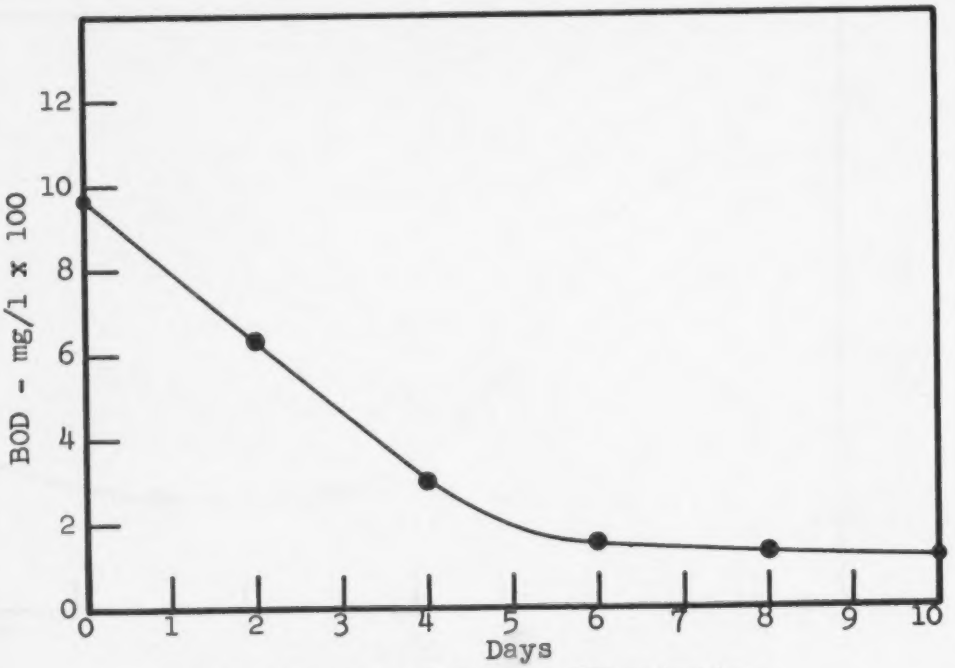

Figure 20. Aerator Study No. 1 - BOD Reduction - Average of 4 Units.

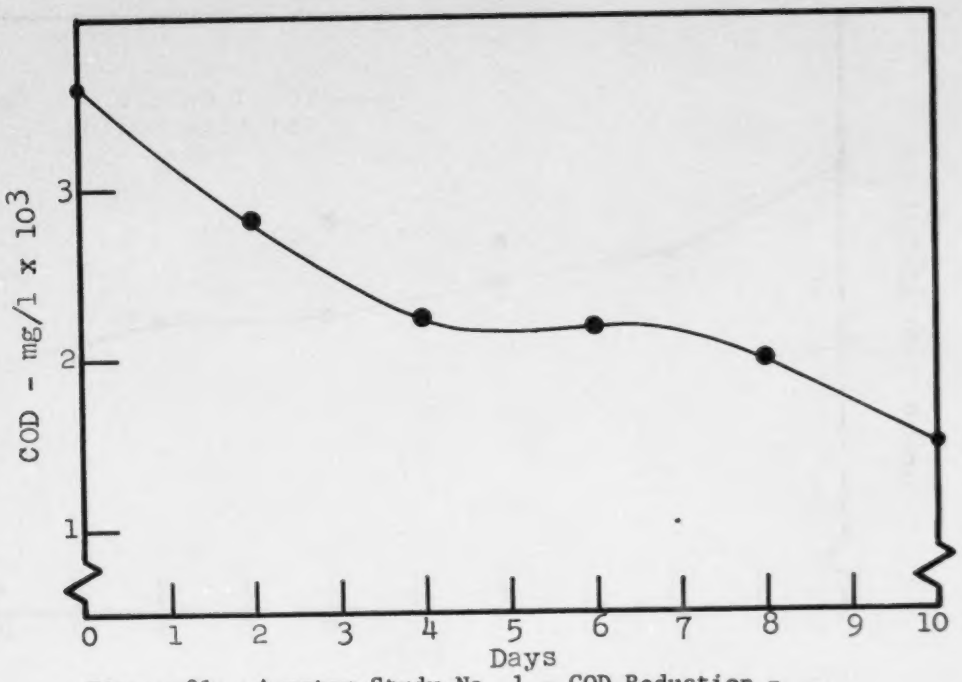

Figure 21. Aerator Study No. 1 - COD Reduction - Average of 4 Units.

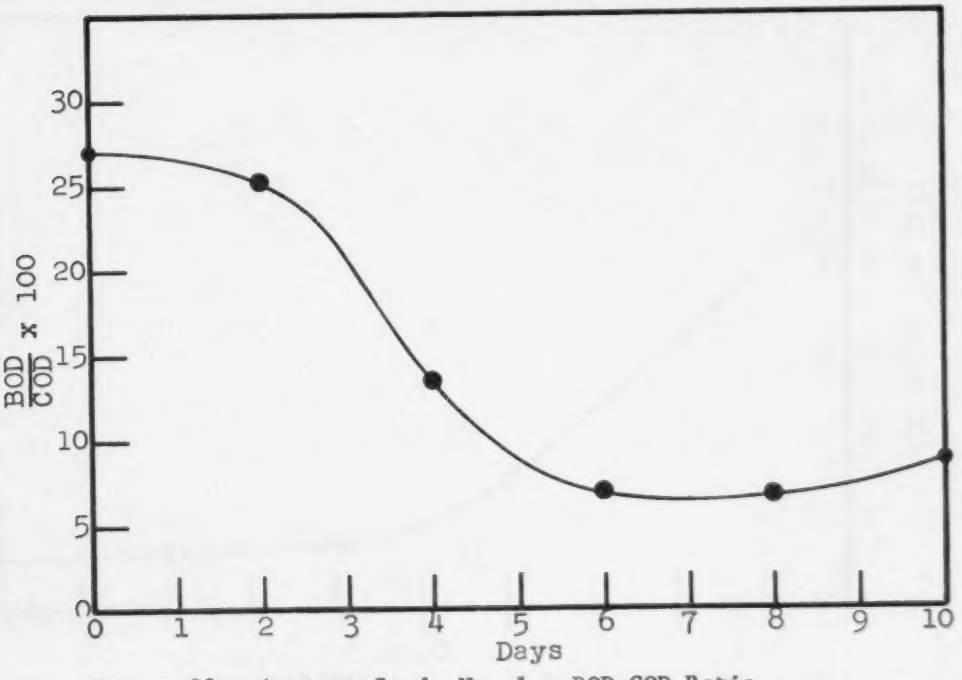

Figure 22. Aerator Study No. 1 - BOD-COD Ratio - Average of 4 Units.

of assimilated material.

A method similar to that used for calculation of solids removed by sampling, was utilized to correct BOD and COD values for the organic content removed by sampling. The BOD and COD could not be related to solids, in the aerator studies, since solids do not remain constant in aeration systems.

Maximum practicable degradation took place in the first six days. This period was therefore taken as the detention time for the next aerator study, in which the aerators were fed once a day.

A theoretical BOD removal for a six-day detention period was computed. Since samples were to be taken before the daily feeding, it was assumed that a given aerator would contain equal volumes of 1, 2, 3, 4, 5, and 6 day old sludge. Thus a sample taken from an aerator being fed 3 grams of dry solids per liter per day, should theoretically have a BOD of

$$1/6 \times 796 = 133 \text{ mg/l}$$
$$1/6 \times 635 = 106 \text{ mg/l}$$
$$1/6 \times 428 = 72 \text{ mg/l}$$
$$1/6 \times 293 = 49 \text{ mg/l}$$
$$1/6 \times 199 = 33 \text{ mg/l}$$
$$1/6 \times 147 = 25 \text{ mg/l}$$
$$418 \text{ mg/l}$$

This amounts to a theoretical reduction of

$$\frac{959 - 418}{959} \times 100 = 56.5 \text{ per cent.}$$

A similar calculation yields a theoretical reduction in COD of 21.8 per cent.

Aerator Study Number 2

The second study was an attempt to approximate a continuous feed system, on six-day detention. The units were started with 10 liters of activated sludge from the Columbia plant, and 2 liters of homogenized hog manure. Two liters per day were withdrawn and replaced with the homogeneous mix. All aerators were given constant air volumes of 1000 cubic feet of air per cubic foot of aerator per day. Aeration tanks 1 through 4 were fed 3, 5, 10, and 20 grams (dry solids basis) per liter per day, respectively. The manure used for this study was homogenized with water to a solids content of 13.86 per cent. The volatile solids content was 96.4 per cent. This slurry was refrigerated, and diluted as necessary for each daily feeding. A 12 day

acclimation period was permitted to elapse before testing began.

Prior to each daily feeding, the freeboards were washed down with tap water and the liquid level brought to the 12 liter mark, to replace evaporation losses. Two liters of the mixed liquor were then siphoned off, and appropriate dilutions made for BOD, COD, and solids analysis.

Results of Aerator Study Number 2

Good agitation and suspension of particulate matter was observed in aerators 1, 2, and 3. Aerator number 4, which was receiving 20 grams dry solids per liter per day, showed much settlement and lack of agitation of particulate matter. Although good BOD reduction was obtained in this aerator, it was believed to be due to settlement. The diffusion device was literally smothered under the solids, and this mass of solids in the bottom of the tank, became foul after the 18th day of operation. Numbers 1 through 3 remained in operation on these loadings for 22 days, and aerobic conditions prevailed.

Samples from all aerators showed good settling characteristics. Figure 23 shows settling characteristics after 30 minutes settling time. Floc from all aerators was heavy and durable. The supernatant from aerators 1, 2, and 3 was clear and sparkling. Supernatant from number 4 was slightly colored.

Results of daily analyses, beginning with the 13th day, are summarized in Table 20. Figure 24 portrays BOD and COD reductions for more ease of comparison.

As might be expected, the aerator receiving the least loading provided the best quality effluent. However, the most efficient loading for this detention period in terms of BOD reduction, is apparently 10 grams dry solids per liter per day. As stated previously, the 20 gram loading provides slightly greater reduction in BOD, however, the accumulation of septic solids in the bottom of the tank would eventually render this system ineffective. It is believed that the greater efficiency of the 10 gram loading is due to the greater quantity of solids, and the consequent frequency of contact between bio-organisms and the substrate. It is also probable that a greater concentration of the substrate will support a greater population of the organisms.

In the number 3 aerator, receiving 10 grams dry solids per day, nearly 70 per cent reduction in BOD was obtained by the end of the 18th day. The reduction in COD was 44.4 per cent.

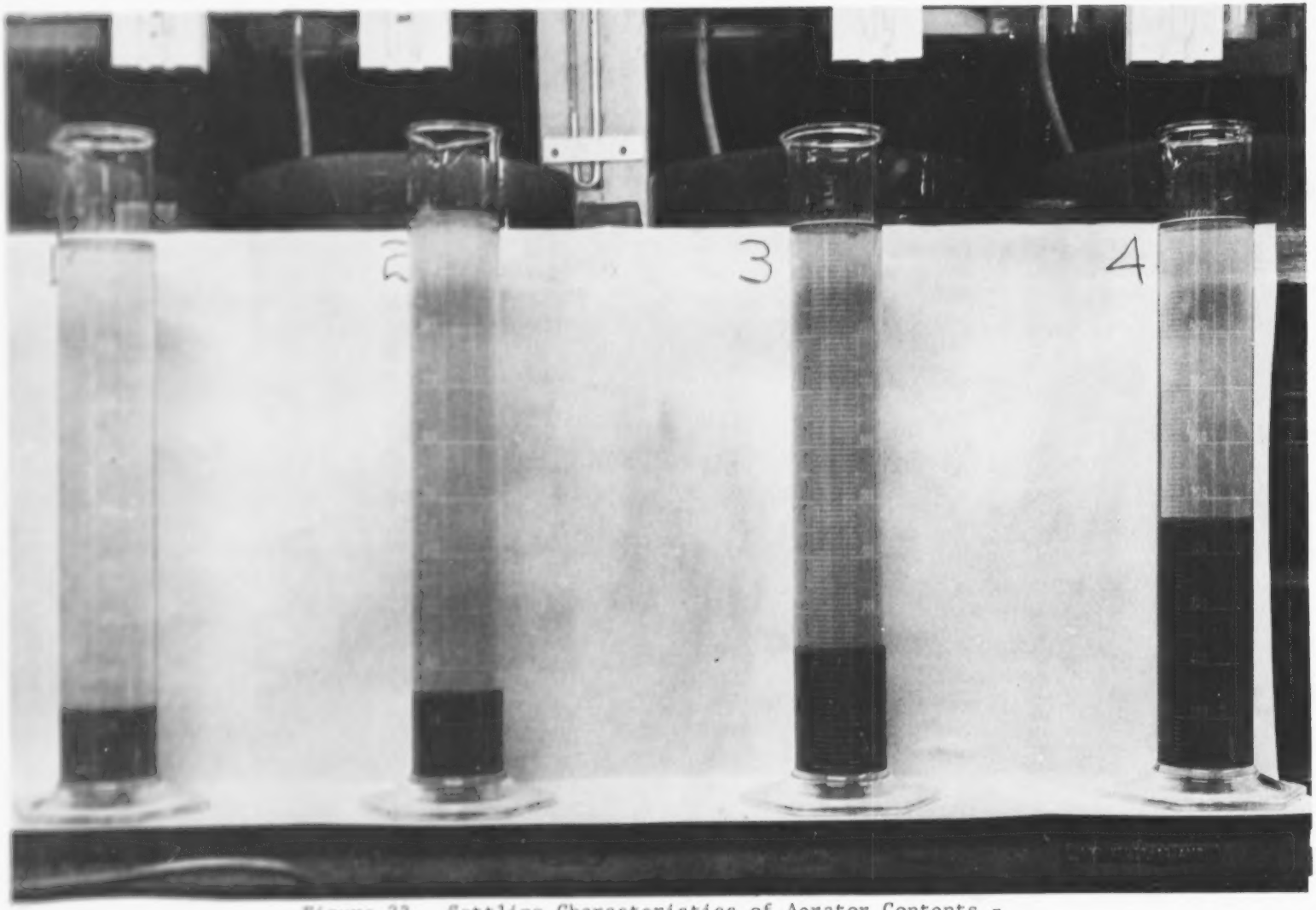

Figure 23. Settling Characteristics of Aerator Contents - Six Day Detention.

Table 20. Results of Aerator Study No. 2 - Six Day Detention.

Unit	Day	BOD Loading mg/l	Effluent BOD mg/l	BOD Reduct. %	COD Loading mg/l	Effluent COD mg/l	COD Reduct. %	Total Solids %	Volatile Solids %	BOD/COD %
1	13	832	640	23.0	4020	4240	-	0.401	80.6	15.2
	14	"	688	17.3	"	4270	-	0.451	66.4	16.1
	15	"	488	41.5	"	3840	4.5	0.405	73.9	12.7
	16	"	468	43.8	"	4000	0.5	0.400	77.4	11.7
	17	"	366	56.1	"	3160	21.4	0.338	73.0	11.6
	18	"	354	57.4	"	3580	10.9	0.335	80.8	9.9
2	13	1385	778	44.0	6700	5810	13.3	0.620	84.5	13.4
	14	"	804	42.1	"	5660	15.5	0.567	69.6	14.2
	15	"	789	43.2	"	5720	14.6	0.509	76.7	13.8
	16	"	728	47.6	"	5310	20.7	0.480	80.1	13.7
	17	"	614	56.0	"	4330	35.4	0.453	75.6	14.2
	18	"	478	66.0	"	5110	23.7	0.434	79.8	9.4
3	13	2770	1057	62.0	13,400	7020	47.6	0.690	86.6	15.1
	14	"	1262	54.5	"	7630	43.0	0.757	74.1	16.6
	15	"	1020	63.2	"	7140	46.7	0.660	77.3	14.3
	16	"	1337	51.9	"	9080	32.2	0.954	86.1	14.7
	17	"	1050	62.2	"	6760	49.5	0.689	78.0	15.5
	18	"	838	69.8	"	7200	46.3	0.623	75.9	11.6
4	13	5540	1495	73.2	26,800	8820	62.1	0.800	77.9	16.9
	14	"	2130	61.8	"	9260	65.5	0.850	71.8	23.0
	15	"	2160	61.2	"	9750	63.6	0.944	74.7	22.2
	16	"	1930	65.4	"	10910	58.3	0.951	79.2	17.7
	17	"	1425	74.5	"	9200	65.6	0.835	74.0	15.5
	18	"	1343	75.6	"	9880	63.1	0.845	74.3	13.6

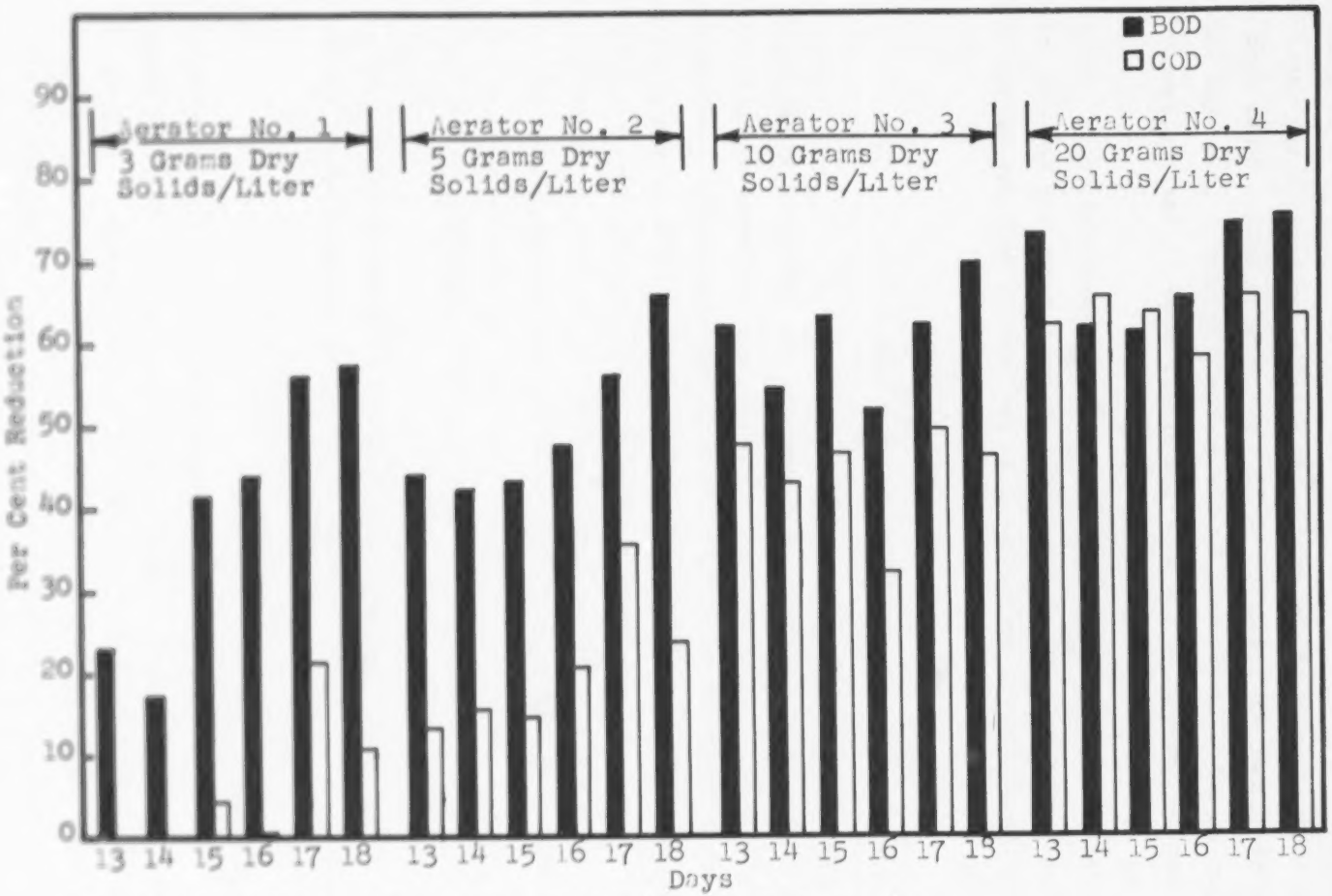

Figure 24. BOD and COD Reduction During Aerator Study No. 2.

Ettinger[28] concludes that the COD represents nearly all of the oxidizable content of a waste. If his conclusion is correct the aeration process oxidized 46.4 per cent of the oxidizable material present in the substrate.

The predicted BOD reduction of 56.5 per cent is within 2 per cent of the reduction actually obtained by the number 1 aerator. Only this one aerator can be compared to the once-fed study, since it had the same solids loading as all aerators in the first study.

The performance of the aerators does not compare well with aeration criteria given by Babbitt[33] for domestic sewage. According to this criteria, the detention period for reduction of 70 per cent in BOD, for aerator number 3 would be

$$0.70 \times 2770 = 20(T \neq 1)$$

or T = 96 hours or 4 days.

Aerator Study Number 3

The purpose of this study was to measure the efficiency of the aeration process utilizing 12 day detention. The loadings, in terms of total solids of hog manure per liter of influent, were the same as for the previous study.

Test methods and technique were identical with those of the previous study. The aerator contents from the previous study were used to start this study. The detention time was simply changed to 12 days, by displacing 1 liter of the mixed liquor each day. A 14 day acclimation period was allowed before the first analyses were made. Zero day, or the beginning of this study, is defined as being the day the operation was changed to 12 day detention.

The number 4 aerator, which had received 20 grams of dry solids per liter per day, was discontinued due to the heavy accumulation of solids in the bottom of the tank.

Results of Study Number 3

The most immediate noticeable change, was a very distinct deterioration in the quality of the floc in the number 1 and 2 units. The floc became light, fluffy, fragile, and much darker in color. Accompanying loss of settling characteristics may be seen in Figure 25. It shows settling characteristics after 30 minutes settling time, on the 7th day, during the acclimation period. Figure 26 shows settling characteristics on the 24th day of operation. Throughout the longer detention period, the quality of

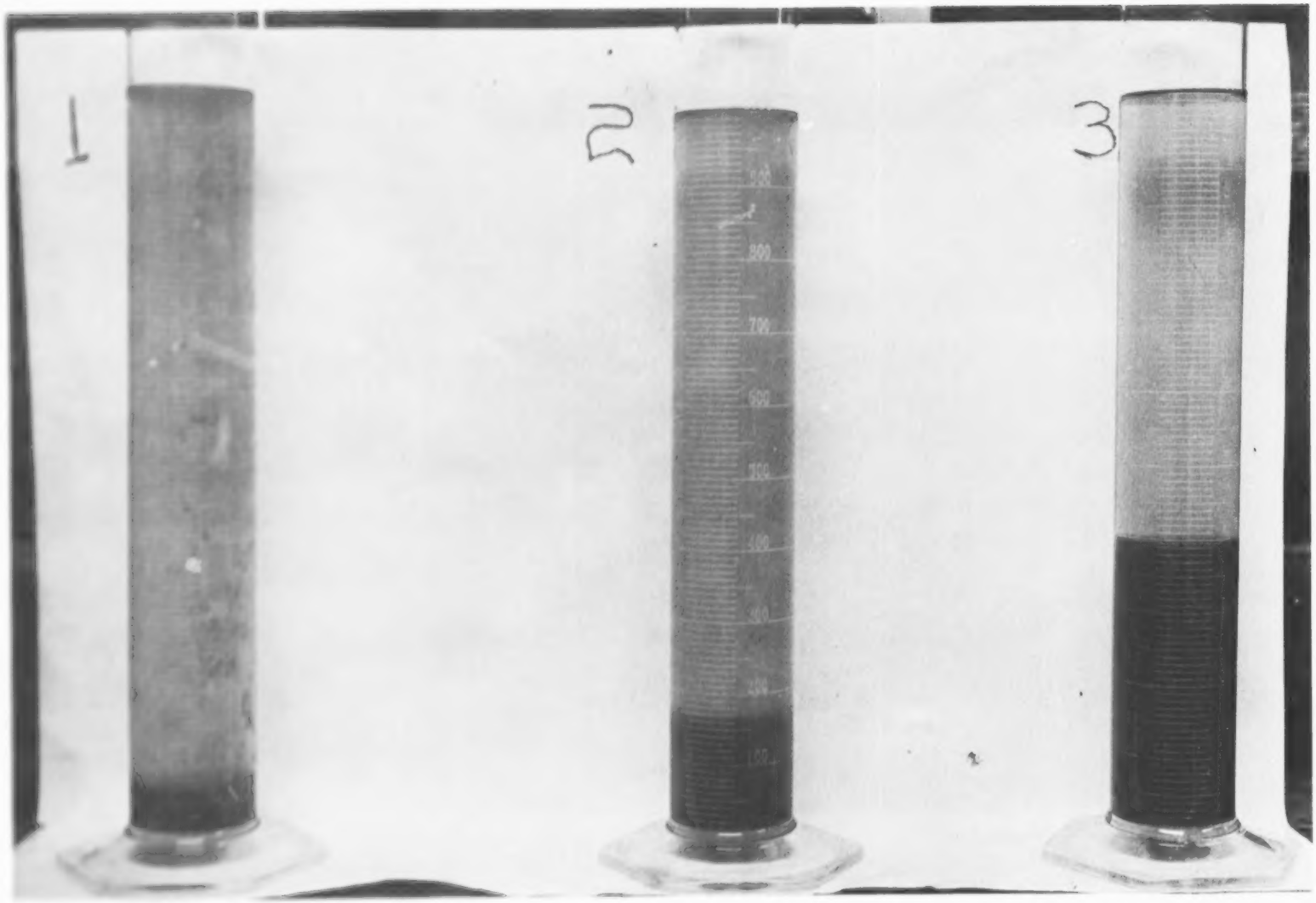

Figure 25. Settling Characteristics of Aerator Contents During Conversion to 12 Day Detention.

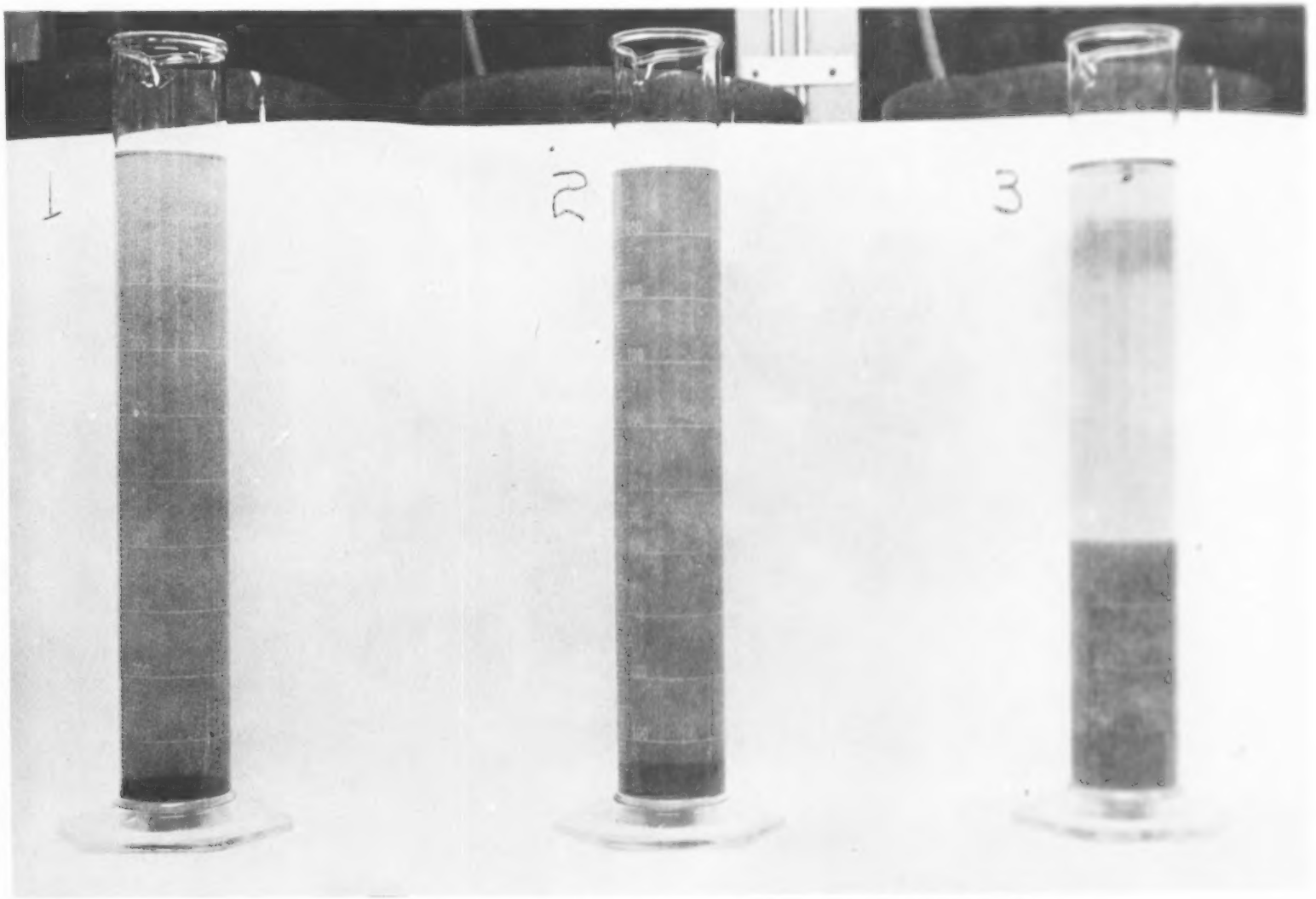

Figure 26. Settling Characteristics of Aerator Contents - 12 Day Detention.

Table 21. Results of Aerator Study No. 3 - Twelve Day Detention.

Unit	Day	BOD Loading mg/l	Effluent BOD mg/l	BOD Reduct. %	COD Loading mg/l	Effluent COD mg/l	COD Reduct. %	Total Solids %	Volatile Solids %	BOD/COD %
1	14	733	263	66.0	5220	2630	49.6	0.247	74.0	10.0
	16	"	163	78.6	"	1960	62.5	0.200	72.7	8.4
	18	"	174	76.1	"	1235	76.4	0.199	78.6	14.1
	20	"	191	73.7	"	1410	73.0	0.199	73.2	13.5
	22	"	172	76.4	"	1510	71.0	0.193	69.4	11.4
	24	"	121	83.3	"	2040	61.0	0.242	83.8	5.9
2	14	1220	319	73.8	8700	3450	60.4	0.350	77.3	9.3
	16	"	404	66.9	"	2920	66.4	0.324	81.0	13.8
	18	"	532	56.4	"	2210	74.5	0.319	79.1	24.0
	20	"	388	68.2	"	2615	69.9	0.290	76.6	14.8
	22	"	357	70.8	"	2710	68.8	0.301	76.3	13.2
	24	"	318	73.9	"	2230	74.2	0.316	82.6	14.3
3	14	2440	1412	42.1	17,400	8250	52.6	0.699	79.9	17.1
	16	"	1117	54.3	"	6290	63.9	0.658	79.0	17.8
	18	"	1481	39.3	"	6200	64.4	0.603	79.9	23.9
	20	"	1111	54.5	"	7690	55.9	0.661	80.5	14.5
	22	"	1110	54.5	"	5760	66.9	0.562	77.8	19.3
	24	"	* 468	-	"	5330	69.4	0.550	81.6	-

* Erratic result

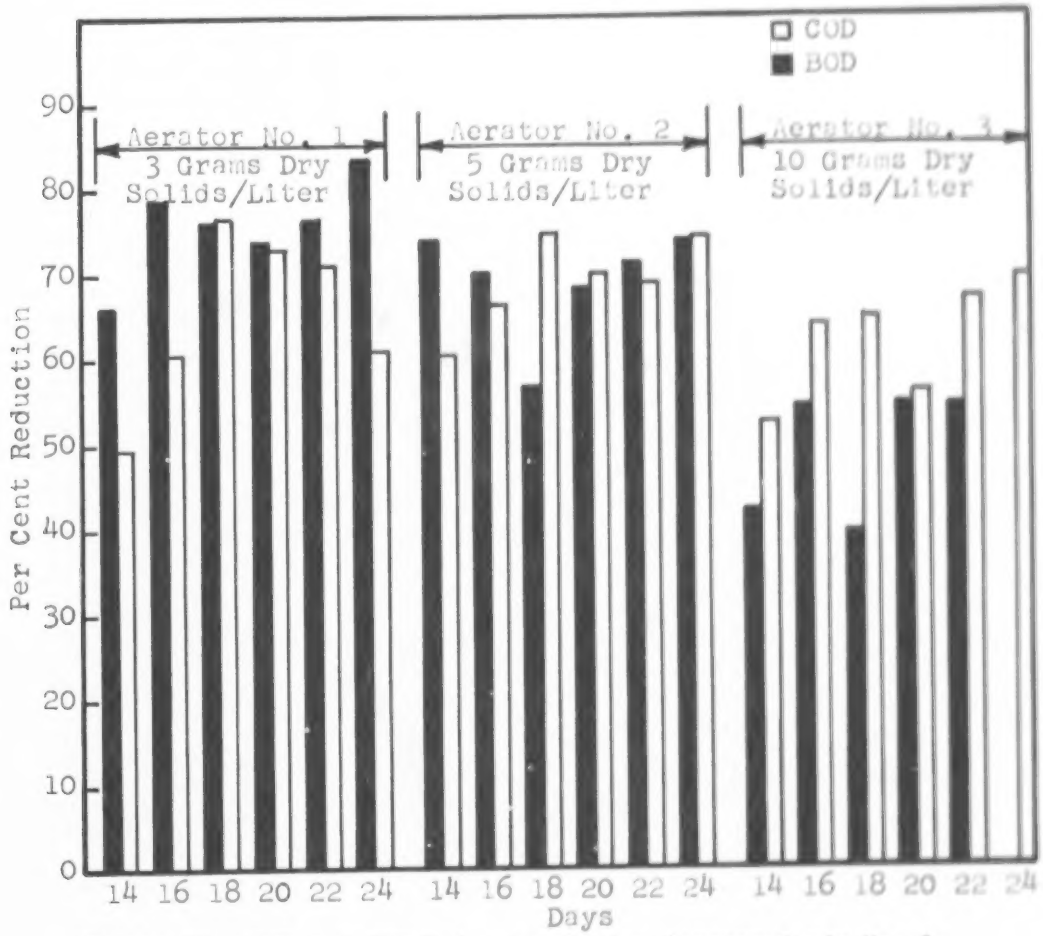

Figure 27. BOD and COD Reduction During Aerator Study No. 3.

floc in aerators 1 and 2 remained poor. The floc in aerator number 3 remained of good quality, however, the supernatant developed a distinct "weak tea" color.

Results of the alternate day analyses are given in Table 21. Figure 27 gives a graphical comparison of BOD and COD reductions obtained by the three units.

Reduction in BOD for units 1 and 2 is seen to be a maximum of 83 and 74 per cent respectively. This compares to maximums of 57 and 66 per cent for the same units in the six-day detention study. This same comparison for the number 3 aerator shows a reduction of 70 per cent for the 6-day detention period and 54 per cent for the 12 day detention. In short, by doubling the detention period, aerator efficiency was improved for the 3 and 5 gram solids loadings, and was lessened for the 10 gram solids loading.

Again, the loading which produced the best quality effluent was the least loaded unit. However, in this study at 12 day detention, aerator number 1 was also the most efficient in terms of BOD removal. No appreciable difference can be seen in efficiency of COD reduction between the three aerators. It is noteworthy that COD reduction is greatly improved over that obtained in the shorter detention period. The maximum BOD reduction was 83.3 per cent and the maximum COD reduction was 76.4 per cent, both of which were attained by the number 1 aerator.

There is no readily apparent explanation for the erratic results obtained for BOD on the 24th day in aerator number 3. Furthermore, there is no readily apparent explanation for the fact that quality of floc, by accepted standards, was definitely inferior to that of the shorter detention period, yet BOD and COD reduction was improved. As can be seen from the tables and figures, aerator number 3 retained floc characteristics similar to those of the shorter detention period, and more nearly conforming to accepted standards, but declined in efficiency of BOD reduction. This leads to speculation that some degradation process of a slightly different nature, perhaps utilizing different organisms, took place in aerators number 1 and 2. The review of the literature failed to disclose similar experience on the part of other investigators.

Conclusions From the Aerator Studies

The conclusions drawn from the aerator studies are:

1. The BOD of hog manure can be reduced by 80 per cent or more, and the COD can be reduced by at least 75 per cent in properly managed continuous or daily fed aerator systems having 12 day detention.
2. The BOD of hog manure can be reduced by about 70 per cent, and the COD by 50 per cent in properly operated aerator systems having 6 day detention.
3. The BOD of hog manure can be reduced by 85 to 90 per cent, and the COD by nearly 60 per cent in batch or once-fed systems having 6 day detention.
4. In once-fed systems, optimum degradation requires about 6 days. Total oxidation of hog wastes is not practicably attainable in batch or continuous-fed systems.
5. Biodegradation of hog wastes proceeds slowly. This is due, in part, to the relatively large particle sizes which are characteristic of the waste.
6. Mathematical extrapolation of biodegradation rates from batch-fed to continuous-fed systems is possible, to the extent shown by the first and second aerator studies.
7. Seven hundred cubic feet of air per cubic foot of aerator per day will suffice for light loadings, however, 1000 cubic feet is needed for agitation, where loadings approach 10 grams dry solids per liter.
8. In continuous-fed systems having a 6 day detention, a loading of 10 grams dry solids per liter provides the most efficient BOD reduction while a loading of 3 grams dry solids per liter provides the better quality effluent.
9. For continuous systems having 12 day detention, loadings of 3 to 5 grams dry solids per liter provide the most efficient BOD and COD reduction and the most satisfactory effluent. Further testing utilizing this displacement period should precede adaption of this criteria for full-scale treatment.
10. Criteria for aeration of domestic sewage is not directly applicable to aeration of hog manure.

CHAPTER 8

LIVESTOCK WASTE TREATMENT CRITERIA

The need for treatment of livestock wastes, to replace disposal practices in concentration feeding operations has been recognized. A stated purpose of this research was the development of treatment criteria. This chapter will present the treatment criteria that can be taken from the results obtained.

Treatment in Anaerobic Lagoons

In the anaerobic digestion studies it was concluded that under controlled conditions at 95°F. and 20 day detention, hog wastes could be digested anaerobically at the rate of .160 lb VS/day/cu ft digester capacity. Assuming a hog excretes 6 pounds of feces per day with a dry solids content of 26 per cent and a volatile solids content of 87 per cent (obtained from averaging the results in Table 16) it is computed that a hog excretes 1.36 lb VS/day.

Six lb feces/day x 0.26 lb TS/lb feces x 0.87 lb VS/lb TS = 1.36 lb VS/day. With these figures it is readily seen that the digester capacity required per hog is 1.36/0.16 or 8.5 cubic feet of digester for the experimental conditions. It may also be computed that 6.25 cu ft digester capacity are required per pound of volatile solids.

It has been found that in domestic sludge digesters in which there is good mixing and temperature control, volatile loadings as high as 0.2 lb VS/day/cu ft digester have been satisfactory and at detentions as low as 10 days. There are many variables that affect the digestion process, such as the total solids concentration in the sludge feed and in the digester, and others, so that it is not possible to compare other work on domestic sludge directly with this study. The point is, however, that for hog waste, approximately 6 cubic feet of digester volume is required per pound of volatile solids, and for the domestic sludge, the corresponding volume requirement is about 5 cubic feet. These figures are similar.

The recommended digestion tank design capacity is much larger than this, however. Heated digesters in primary treatment plants (sedimentation only) are designed for 2 to 3 cubic feet of tank per capita.[35] The per capita contribution of volatile solids to the digester is easily computed knowing

that the suspended solids produced per capita per day is 0.20 lbs,[36] that about 50 per cent of these are removed in the settling tank, and that approximately 70 per cent is volatile material. The calculation is:

0.20 lb SS/cap/day x 50% removal to digester x 70% volatile material = 0.07 lb volatile suspended solids (VSS) per capita per day to digester.

In actual practice therefore, digesters are designed for 2 cu ft tank/0.07 lb VSS, or 28.6 cu ft tank/lb VSS. This is a relatively large figure compared to the 5 cubic feet value mentioned above.

For unheated digesters in domestic sludge treatment, the design capacities are twice the values for heated digesters, or 4 to 6 cu ft/cap. These values can be extrapolated to hog waste digester design by using the figures 0.07 and 1.36 lb VS/day/capita and per hog respectively. It is calculated as follows:

$\frac{1.36}{0.07}$ x 4 cu ft = 78 cu ft unheated digester volume required per hog.

Therefore, an unheated digester for hog wastes designed on criteria used for domestic sludge digester design, would require 78 cubic feet per hog. It appears from this calculation that even the lagoons presently in use, that are designed at 15 square feet per hog and 3 to 4 feet deep, do not quite meet volume requirements for anaerobic digesters.

Treatment in Aerobic Lagoons

As stated previously, hog waste lagoons designed on the 15 square feet per hog criteria, are grossly overloaded by domestic sewage lagoon standards.

The data collected in the livestock waste characteristics study permits calculation of the requirements for a lagoon in which aerobic conditions would prevail.

For lagoons, data for domestic sewage can probably be extrapolated directly, or nearly so, to hog waste. Domestic lagoons have been operated successfully at loadings of 50 pounds of BOD per acre per day, or 872 square feet per pound of BOD per day. Thus the requirement per fattening hog would be:

872 sq ft/lb BOD/day x 0.438 lb BOD/hog/day

or 382 square feet of lagoon surface per hog. This is equivalent to

$\frac{43,560}{382}$ = 114 hogs per acre of lagoon.

On this basis, a confinement feeding operator, feeding 1000 head of hogs would find it necessary to devote nine acres of his land to a lagoon. When present day land prices are considered, the cost of maintaining a lagoon under aerobic conditions becomes a very real consideration. Conversely, such an installation should require a minimum of maintenance, be free of odor nuisance, and eliminate any health hazard due to pollution of ground water or surface water.

A lagoon of this size, in Missouri, would have evaporation losses of up to 4 feet per year, 3 feet of which would occur during the three summer months. This would necessitate a daily water supply, during those months, of:

$$\frac{9 \text{ acres} \times 43{,}560 \text{ sq ft/acre} \times 3 \text{ ft} \times 7.48 \text{ gal/sq ft}}{90 \text{ days}}$$

= nearly 100,000 gallons per day.

It should be evident that few Missouri farms have the capability of supplying this water demand.

Calculations similar to those given above may be performed, in order to arrive at the required area for aerobic lagoons serving other numbers of hogs or for cattle or sheep.

Treatment in Multi-celled Lagoons

In Chapter 6 it was stated that the two-celled lagoon was being employed in this investigation. This operation does not eliminate all of the nuisance and health hazard concomitant with a septic lagoon. As stated previously septic conditions prevail in the first cell. The liquid is black, foul and roiled by gas production.

As discussed in Chapter 6, this study has been hampered by a water shortage, and insufficient displacement into the second cell precludes a precise conclusion at the time of this writing.

On the basis of knowledge already gained from this project, the confinement feeding operator may provide a two-celled lagoon with reasonable assurance that he will create no water pollution problem, other than that due to seepage from the cells. The latter problem may or may not manifest itself in any lagoon project, regardless of the number of cells or size of lagoon.

The land area requirement calculation is relatively simple:

15 sq ft/hog/cell x 2 cells = 30 sq ft/hog.

Approximately 20 per cent should be added to this area for embankments. Thus for a 1000 hog operation:

1.20 x 30 sq ft/hog x 1000 = 36,000 square feet

or 0.825 acres would be required. The water requirement would be 3500 gallons per day, during the three summer months. This quantity of water would, theoretically, displace only the evaporation and there would be no effluent.

The addition of a third, or still more cells would improve all conditions discussed. It is possible that, by experimentation, there could be determined the optimum number of cells.

Treatment by Fill-and-Draw Aerator

The results of the first aerator study suggest the suitability of once-fed batch, or fill-and-draw aerators for treatment of livestock waste. Hog manure will be used to illustrate the development of this criteria. The choice between this type of system and a continuous system would be the result of consideration of several factors. For example, a continuous system would necessarily require that the hogs be placed on grates, over the aerator. This would, for all practical purposes, involve the construction of an entirely new operation, since it would be difficult to construct aerators under existing sheds. A fill-and-draw system, conversely, could be added to an existing swine feeding layout.

Assuming that, for convenience of operation, a 7 day schedule is adopted, the data taken from the first aerator study would apply.

It has been shown that a fattening hog excretes about 6 pounds of fecal matter per day, of which 26 per cent is solid matter. Thus, the volume of aerator required per hog per day would be:

$$\frac{6.0 \text{ lb/hog/day} \times .26 \times 453.6 \text{ gms/lb}}{3 \text{ gms/l}} = 236 \text{ l/hog/day.}$$

On a 7 day basis, this volume would be:

$$\frac{236 \text{ l/day/hog} \times 7 \text{ days}}{28.32 \text{ l/cu ft}} = 58.4 \text{ cu ft/hog.}$$

For a 1000 hog operation, 58,400 cubic feet of aerator volume would be required.

For this size operation, the air requirement based on 700 cu ft air/day/cu ft aerator volume would be:

700 cu ft/cu ft x 58,400 = 40.9 x 10^6 cu ft/day.

This would require a blower or blowers having a capacity of 28,000 cubic feet per minute, at 10 pounds per square inch static pressure.

The water requirement, which would of necessity require availability in a period of a few hours, would be:

58,000 cu ft x 7.48 gal/cu ft = 434,000 gal/week.

A slight adjustment of these figures to provide for retaining about 10 per cent seed material, after each withdrawal, would be advisable.

For an operation of this scale, the operator might find it convenient to divide the total requirements, above, into three or four aerators, thus having one aerator for each day on which pens are cleaned. Otherwise, some manure would be stockpiled for as long as 7 days.

It is also probable that solids loadings could be increased, with successful biodegradation results, provided that overflow of foam was not considered to be objectionable. This should be verified by bench-scale testing.

The configuration of the unit or units would, of necessity, depend upon the configuration of the diffuser equipment to be used, and upon the number of units. In general, the longitudinal cross section of the tank or tanks should be square, with chamfered corners, to provide the mixed liquor with a good rolling motion.

Calculations similar to those given above, may be used to arrive at the requirements for any number of hogs.

Treatment by Continuous-fed Aerators

As stated in Chapter 7, verification of the results obtained for 12 day detention should be accomplished prior to full-scale use of that criteria. Assuming such verification, the following development is presented.

The continuous feed system is particularly adaptable to the slotted floor operation where no labor for clean up is required and the water requirements can be met over the entire day rather than during washdown operations. In this set up the liquid surface area would be the same as the pen floor area, and all excrement would drop directly into the aeration tank.

Again, a fattening hog excretes about 6 pounds of fecal matter, of which 26 per cent is solid matter. In this system it would also be necessary to include the loading due to urine. The biodegradation rate of urine in

aerators is not known, however the magnitude of this loading is small compared to that of the feces and will therefore be considered to be the same as that of the feces. Then the volume of aerator required per hog per day would be:

$$\frac{(6.0 \text{ lb/hog/day} \times .26 + 3.3 \text{ lb/hog/day} \times .03)}{\frac{5 \text{ gm/l}}{453.6 \text{ gm/lb}}}$$

= 150.5 l/hog/day.

For a 12 day detention period, this volume equals

$$\frac{150.5 \text{ l/hog/day} \times 12 \text{ days}}{28.32 \text{ l/cu ft}} = 63.8 \text{ cu ft/hog.}$$

With hogs on grates having 15 square feet per hog, the aerator would require 4.25 feet of depth.

This system would require

700 cu ft air/cu ft aerator x 63.8 cu ft/hog

or 44,800 cubic feet of air per day per hog. Again taking a 1000 hog operation as an example, a blower or blowers capable of delivering 31,000 cubic feet per minute would be required. In this case, with only 4.25 feet depth in the tank, the static pressure requirement, depending upon length of pipes, bends, and other head losses, should not exceed 5 pounds per square inch.

The water requirement would be very nearly that of the batch-fed system, however, delivery would not be required in just a few hours, as is the case with the batch-fed system. Assuming a constant water input, the requirement would be:

$$\frac{63{,}800 \text{ cu ft} \times 7.48 \text{ gal/cu ft}}{12 \text{ days}} = 39{,}800 \text{ gal/day.}$$

These calculations may be altered to give the requirements for any number of hogs, or for the shorter detention period.

In the event the 6 day detention period is chosen, the loading should be increased to 10 grams dry solids per liter. This loading would decrease the depth of the aerator to slightly more than 1 foot. In this case difficulty would be encountered in obtaining the rolling motion, which is necessary in aerator tanks, and it would be necessary to either use the same depth as before under the slotted floor and decrease the surface area, or utilize a "remote" aeration tank.

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APPENDIX

APPENDIX A

Summary Data for Each Digester in Anaerobic Digestion Study

TABLE A-1
Summary Data
Hog Waste Digestion Study No. 2
14 Day Average of Digester No. 3

	Time-days							
	1-10	11-24	25-38	39-52	53-66	67-80	81-94	95-111
Raw sludge:								
Total solids (%)	6.80	6.59	6.41	6.11	5.74	5.68	6.34	6.95
Volatile solids (%)	71.0	71.8	76.0	80.3	84.4	86.9	88.5	89.0
pH	5.8	6.1	6.1	6.1	6.1	6.0	6.0	6.0
Loading:								
TS (lb/day/1000 cu ft dig.)	213	208	200	190	179	177	199	218
VS (lb/day/1000 cu ft dig.)	151	149	152	153	151	154	176	194
Operating conditions:								
Gas prod. (cu ft/day)	.155	.183	.180	.180	.177	.185	.202	.164
Gas prod. (cu ft/lb VS added)	7.25	8.77	8.40	8.32	8.27	8.53	8.15	6.03
Digester temperature (^{o}C)	35.5	35.5	35.5	35.5	35.5	35.5	35.5	35.5
pH	7.3	7.3	7.4	7.4	7.3	7.4	7.5	7.4
Volatile acids (mg/l)	65	130	182	96	77	124	514	3020
Digested sludge								
Total solids (%)	3.12	3.74	4.03	4.08	3.83	3.31	2.97	3.18
Volatile solids (%)	52.6	54.3	55.7	59.5	64.9	68.1	70.7	74.3
TS (lb/1000 cu ft dig.)	98	117	126	128	120	104	93	99
VS (lb/1000 cu ft dig.)	52	64	70	76	78	71	66	74
Reduction in TS (%)	54.2	39.0	37.0	32.7	33.0	41.5	53.2	54.7
Reduction in VS (%)	66.0	57.3	53.7	50.2	48.4	54.0	62.6	61.8
Gas prod.(cu ft/lb VS des.)	11.0	15.2	15.5	16.5	17.1	15.7	13.0	9.65

TABLE A-2
Summary Data
Hog Waste Digestion Study No. 2
14 Day Averages of Digester No. 4

	Time-days							
	1-10	11-24	25-38	39-52	53-66	67-80	81-94	95-111
Raw sludge:								
Total solids (%)	6.80	6.59	6.41	6.11	5.74	5.68	6.34	6.95
Volatile solids (%)	71.0	71.8	76.0	80.3	84.4	86.9	88.5	89.0
pH	5.8	6.1	6.1	6.1	6.1	6.0	6.0	6.0
Loading:								
TS (lb/day/1000 cu ft dig.)	213	208	200	191	179	177	199	218
VS (lb/day/1000 cu ft dig.)	151	149	152	153	151	154	176	194
Operating conditions:								
Gas prod. (cu ft/day)	.156	.177	.172	.164	.176	.196	.206	.169
Gas prod. (cu ft/lb VS added)	7.32	8.49	8.02	7.60	8.25	9.02	8.30	6.21
Digester temperature (^{o}C)	35.5	35.5	35.5	35.5	35.5	35.5	35.5	35.5
pH	7.3	7.4	7.4	7.4	7.3	7.4	7.4	7.4
Volatile acids (mg/l)	341	217	204	252	166	128	514	3600
Digested sludge								
Total solids (%)	3.10	3.64	3.97	3.99	3.81	3.39	3.10	3.20
Volatile solids (%)	53.0	54.5	55.9	60.2	65.5	68.8	71.8	74.9
TS (lb/1000 cu ft dig.)	106	114	124	125	120	106	96	99
VS (lb/1000 cu ft dig.)	56	62	69	75	78	73	70	73
Reduction in TS (%)	50.2	40.4	38.1	34.6	33.0	40.2	51.8	54.5
Reduction in VS (%)	64.4	58.2	55.0	50.8	48.1	52.4	61.1	62.0
Gas prod.(cu ft/lb VS des.)	11.3	14.4	14.7	14.9	17.1	17.1	13.7	9.85

TABLE A-3
Summary Data
Cow Waste Digestion Study No. 1
16 to 20 Day Averages of Digester No. 3

	Time-days			
	29-49	50-66	67-85	86-107
Raw sludge:				
Total solids (%)	4.43	4.23	4.51	5.27
Volatile solids (%)	88.9	88.6	87.3	87.0
pH	5.8	6.2	6.4	6.4
Loading:				
TS (lb/day/1000 cu ft dig.)	174	198	212	248
VS (lb/day/1000 cu ft dig.)	155	176	185	216
Operating conditions:				
Gas prod. (cu ft/day)	.065	.076	.057	.082
Gas prod. (cu ft/lb VS added)	2.96	3.08	2.15	2.69
Digester temperature (^{o}C)	36.0	36.0	36.0	36.0
pH	7.1	7.1	7.0	7.0
Volatile acids (mg/l)	187	161	211	218
Digested sludge				
Total solids (%)	3.79	3.45	3.46	3.86
Volatile solids (%)	74.2	83.2	85.0	84.6
TS (lb/1000 cu ft dig.)	119	108	108	122
VS (lb/1000 cu ft dig.)	88.2	90.0	92.3	103
Reduction in TS (%)	31.6	45.4	49.1	50.8
Reduction in VS (%)	40.5	48.8	44.6	52.2
Gas prod.(cu ft/lb VS des.)	6.87	6.22	4.32	5.66

TABLE A-4
Summary Data
Cow Waste Digestion Study No. 1
16 to 20 Day Averages of Digester No. 4

	Time-days			
	29-49	50-66	67-85	86-107
Raw sludge:				
Total solids (%)	4.43	4.23	4.51	5.27
Volatile solids (%)	88.9	88.6	87.3	87.0
pH	5.8	6.2	6.4	6.4
Loading:				
TS (lb/day/1000 cu ft dig.)	174	198	212	248
VS (lb/day/1000 cu ft dig.)	155	176	185	216
Operating conditions:				
Gas prod. (cu ft/day)	.065	.073	.052	.072
Gas prod. (cu ft/lb VS added)	2.95	3.02	1.99	2.34
Digester temperature (^{o}C)	36.0	36.0	36.0	36.0
pH	7.2	7.1	7.0	7.0
Volatile acids (mg/l)	140	164	228	134
Digested sludge				
Total solids (%)	3.70	3.52	3.40	3.73
Volatile solids (%)	75.6	83.1	85.0	84.7
TS (lb/1000 cu ft dig.)	116	110	118	117
VS (lb/1000 cu ft dig.)	87.8	91.9	90.7	99.1
Reduction in TS (%)	33.4	44.5	44.4	53.0
Reduction in VS (%)	43.4	47.8	51.0	54.5
Gas prod.(cu ft/lb VS des.)	5.94	6.09	3.84	4.34

TABLE A-5
Summary Data
Sheep Waste Digestion Study No. 1
14 Day Averages of Digester No. 3

	Time-days							
	1-14	15-28	29-42	43-56	57-70	71-84	85-98	99-112
Raw sludge:								
Total solids (%)	5.19	5.00	5.95	6.07	5.87	6.38	5.62	6.26
Volatile solids (%)	77.8	79.5	80.0	82.0	83.4	75.3	89.8	90.3
pH	6.0	6.0	6.0	5.8	5.7	5.9	6.8	6.8
Loading:								
TS (lb/day/1000 cu ft dig.)	125	155	186	181	184	199	176	195
VS (lb/day/1000 cu ft dig.)	97	123	149	148	153	140	158	176
Operating conditions:								
Gas prod. (cu ft/day)	.106	.158	.164	.143	.122	.080	.064	.052
Gas prod. (cu ft/lb VS added)	7.81	9.10	7.83	6.86	5.64	3.82	2.88	2.11
Digester temperature (^{o}C)	35.1	35.2	35.2	35.1	35.2	35.2	35.2	35.1
pH	7.4	7.4	7.4	7.4	7.3	7.3	7.2	7.1
Volatile acids (mg/l)	80	83	72	80	154	88	100	110
Digested sludge								
Total solids (%)	2.33	2.65	3.01	3.44	3.80	4.06	4.28	4.63
Volatile solids (%)	59.7	61.0	64.3	67.9	71.2	73.7	76.3	82.0
TS (lb/1000 cu ft dig.)	72.7	82.3	94.0	107	119	127	134	145
VS (lb/1000 cu ft dig.)	43.4	50.1	60.3	72.5	84.6	93.5	102	119
Reduction in TS (%)	42.2	46.9	49.5	40.9	35.3	36.2	23.9	25.6
Reduction in VS (%)	55.3	59.3	59.7	51.5	44.7	37.6	35.5	32.4
Gas prod.(cu ft/lb VS des.)	14.1	15.4	13.1	13.5	12.5	10.1	7.90	6.50

TABLE A-6
Summary Data
Sheep Waste Digestion Study No. 1
14 Day Averages of Digester No. 4

	Time-days							
	1-14	15-28	29-42	43-56	57-70	71-84	85-98	99-112
Raw sludge:								
Total solids (%)	5.19	5.00	5.95	6.07	5.87	6.38	5.62	6.26
Volatile solids (%)	77.8	79.5	80.0	82.0	83.4	75.3	89.8	90.3
pH	6.0	6.0	6.0	5.8	5.7	5.8	6.8	6.8
Loading:								
TS (lb/day/1000 cu ft dig.)	125	155	186	181	184	199	176	195
VS (lb/day/1000 cu ft dig.)	97	123	149	148	153	150	158	176
Operating conditions:								
Gas prod. (cu ft/day)	.101	.157	.159	.128	.115	.076	.055	.059
Gas prod. (cu ft/lb VS added)	7.46	8.96	7.60	6.90	5.30	3.59	2.49	1.79
Digester temperature (^{o}C)	35.1	35.2	35.2	35.1	35.2	35.2	35.2	35.1
pH	7.4	7.4	7.4	7.4	7.3	7.3	7.2	7.1
Volatile acids (mg/l)	94	94	60	81	130	101	110	100
Digested sludge								
Total solids (%)	2.36	2.67	2.95	3.42	3.73	4.02	4.14	4.52
Volatile solids (%)	59.2	62.0	64.1	67.9	71.5	73.2	76.3	82.6
TS (lb/1000 cu ft dig.)	73.6	83.5	92.1	107	117	126	130	141
VS (lb/1000 cu ft dig.)	43.5	51.7	59.0	72.5	83.7	92.2	99.0	116
Reduction in TS (%)	41.0	46.2	50.5	40.8	36.4	36.7	26.1	27.7
Reduction in VS (%)	55.2	57.9	60.3	51.0	45.3	38.5	37.3	34.1
Gas prod.(cu ft/lb VS des.)	13.5	15.5	12.6	13.5	11.7	9.30	6.66	5.25

APPENDIX B

Standardization of Micro-Kjeldahl Analysis

Standardization of Micro-Kjeldahl Analysis
August 23, 1962

One gram of CH_2NH_3COOH (glycine) was dissolved in 1 liter of distilled water (titre, 1 ml = 1 mg glycine) and a Kjeldahl determination was made. The following data and results were obtained:

Run No.	1	2	3	4	5	6
Chemicals used	A	B	A	B	A	B
Volume of sample	0	0	5	5	10	10
ml of 0.002N H_2SO_4 used	0.2	0.2	34.3	35.2	67.7	66.7
NH_3-N mg/l			192	195	188	185

Computations:

1 ml sample = 1 mg glycine = 14/76 or 0.184 mgN or 184 mg/l N

$$NH_3\text{-N (mg/l)} = \frac{(\text{ml of } 0.002N\ H_2SO_4) \times 0.028 \times 1000}{\text{Size of sample (ml)}}$$

Sample conputation: Run No. 3

$$\text{mg/l } NH_3\text{-N} = \frac{(34.3 - 0.2)0.028 \times 1000}{5 \text{ ml}} = 192 \text{ mg/l}$$

Run No. 1 and 2 were blanks and distilled water was used instead of a sample. In the remaining runs, glycine was used. "Chemical A" indicates the use of 0.65 g. of potassium sulfate, 0.016 g. of mercuric oxide, and 1.0 ml of concentrated sulfuric acid. "Chemical B" indicates the use of 1 g. of potassium sulfate, 0.046 g. of mercuric oxide, and 1.0 ml of concentrated sulfuric acid. In Chemical B, the dry chemicals were already mixed together and only one weighing was necessary. Using the dry mixed powder, it was determined that the volumetric measurements of the powder would be much faster and sufficiently accurate.

The theoretical value was 184 mg/l. In Runs 4 and 6, using chemical B, the smallest and largest errors were obtained.

APPENDIX C

Computation of Probable Error in BOD Determinations

Computation of Probable Error in BOD Determinations

A theoretical probable error, to take into consideration laboratory errors, was computed as follows:

E_1 = Probable error in weighing specimen

= 0.5 ml/10 ml x 100 = 5.00

E_2 = Probable error in dilution

= 5 ml/1000 ml x 100 = 0.50

E_3 = Probable error in weighing wet solids sample

= 0.5 gms/60 gms x 100 = 0.83

E_4 = Probable error in initial DO determination

= 0.1 ml/7 ml x 100 = 1.43

E_5 = Probable error of 1° in incubation temperature

= 0.04 x .262/.262 x 100 = 4.00

E_6 = Probable error in weighing dry solids

= 0.0005 gms/0.020 gms x 100 = 2.50

E_7 = Probable error in final DO determination

= 0.1 ml/3 ml x 100 = 3.33

Then, $E_p = \sqrt{(E_1)^2 + (E_2)^2 + \ldots . (E_n)^2}$

$= \sqrt{(5.00)^2 + (0.50)^2 + \ldots (3.33)^2}$

$= \sqrt{61.33}$

= 7.8 per cent

The actual variations in BOD in terms of total solids was plus 20.6 per cent, and minus 28.8 per cent.

APPENDIX D

BOD, COD, and Dissolved Oxygen Determinations in Lagoon Study

As stated in Chapter 6, the lagoon study was continued into the summer months of 1963. As late as mid-July, there had been no measurable discharge from the secondary lagoon. The appearance of both cells remained essentially, as previously described.

Measurement of DO, BOD, and COD in both cells was made and the results are as follows:

	Primary Lagoon		Secondary Lagoon		
Date	BOD mg/1	COD mg/1	BOD mg/1	COD mg/1	DO mg/1
6-19	180	1885	35	434	10.2
6-21	206	1880	24	422	14.6
6-25	247	1885	36	470	0.0**
6-27	280	2460	31	447	24.0
7-1	170	2195	9	350	17.7
7-3*	197	2195	29	650	17.1

* Samples taken after 1.6 in. rain fell in approximately 2 hours.
** Sample taken 12 in. below the surface.

Samples were taken immediately below the surface near the discharge pipe except on July 1. The samples on this date were taken approximately 12 inches below the surface in both lagoons. Prior to a rain on July 2, the water level in both lagoons was below the discharge pipes. Subsequent to the rain, both lagoons were full. There had been some discharge from the primary cell into the secondary cell, and this may account for the increase in BOD of the secondary lagoon. The dissolved oxygen content in the lagoons was zero except for the top few inches in the secondary lagoon.